At the time of issue this report has not been published. Any author desiring to quote this paper should refer to it as "A paper of the Meteorological Research Committee (London), M.R.P. No. 863 by Mr. F.H. Bushby and Miss M.K. Hinds. A copy is available in the Library of the Meteorological Office"

M.R.P. 863
S.C.II/169
26th May, 1954

AIR MINISTRY

METEOROLOGICAL RESEARCH COMMITTEE

A Preliminary Report on Ten Computed Sets of Forecasts Based on the Sawyer and Bushby Two-Parameter Atmospheric Model

by
F.H. Bushby and Mavis K. Hinds (Meteorological Office)

1. Introduction

In a recent paper Bushby and Hinds (1954) have presented the results of the first two sets of 12-hr and 24-hr computed forecasts of the 500 mb and 1000 mb contour charts and the 1000-500 mb thickness charts using the Sawyer-Bushby (1953) two-parameter model atmosphere. The results were sufficiently good to justify performing the elaborate computations for a further ten synoptic situations in order to ascertain the effects of the limitations of the model.

The present paper gives a descriptive account of the results of these ten computations. Suggestions are made of the way in which certain limitations of the two-parameter model could possibly account for some of the discrepancies between the computed and actual charts, but until these limitations have been removed and the calculations repeated, it is not possible to be definite about this matter.

Correlation coefficients have been evaluated between the observed 24-hr changes and the computed 24-hr changes, and regression equations have been worked out. This has been repeated with the 24-hr forecast charts prepared by conventional methods in the Forecasting Branch, Dunstable, in an attempt to compare these two methods of forecasting.

2. The Method

The method of solution is essentially the same as that described by Bushby and Hinds (1954), but 1-hr time-steps were used throughout the computation in order to eliminate the effects of computational instability. In certain of the summer situations a longer time-step might have been satisfactory, but it was thought best to introduce a uniform procedure for this series of calculations. The actual time integration formulae used were:-

$$H_1 = H_0 + \left(\partial H/\partial t\right)_0 \delta t \qquad \text{(1)}$$

$$H_{n+1} = H_{n-1} + 2\left(\partial H/\partial t\right)_n \delta t \qquad \text{(2)}$$

where H_n represents a value of the 500 mb contour height or 1000-500 mb thickness at time $t + n\delta t$, and t is the time to which the initial data of the computation refer.

Nine of the ten computations were performed on LEO, the electronic computing machine owned by J. Lyons and Co., and the tenth by a Ferranti machine at Manchester University. The machine time (including output) per time step was $8\frac{1}{2}$ minutes, irrespective of which machine was used.

The ten situations were chosen so as to cover a wide range of synoptic conditions.

3. Results

(a) 1500 GMT 8 Jan., 1951

The most significant feature of the synoptic situation during the 24 hours commencing 1500 GMT 8 Jan., 1951 was the development of a depression from a small trough associated with a frontal system in mid-Atlantic. This depression became moderately deep and moved to 47°N 12°W by the end of the period. It was associated with a developing thermal trough and a cut-off depression at 500 mb.

This development was not indicated by the computed charts (see Figs. 1a-j). The weak 500 mb trough in existence at the commencement of the period was certainly computed to intensify, but the main vortex was forecast too far NNE. The forecast 1000-500 mb thickness trough was about 5° too far east and the absolute values were much too low, almost certainly due in part to the neglect of the non-adiabatic heating over the warm sea. Thus the computed 1000 mb chart for 1500 GMT 9 Jan., 1951 bore very little resemblance to the actual synoptic situation. During the forecast period a considerable change took place on the northern half of the western boundary and this may have contributed towards the failure of the computed forecast.

The forecasts produced by the conventional methods of the Forecast Division, Dunstable, for this period contained similar errors in the region of the British Isles to those of the computed charts.

(b) 1500 GMT 10 Aug., 1951

This situation was one in which a depression centred at 54°N 24°W associated with a thermal trough moved eastwards to North Wales during the ensuing 24-hr period. This movement was calculated quite well (Figs. 2a-j) although the calculated deepening of the depression was a little too much. The computed 500 mb pattern also agreed closely with the actual pattern, although the 500 mb ridge in mid-Atlantic was computed to be too intense and this was reflected in the intensity of the computed 1000 mb ridge. The over-development of the mid-Atlantic contour ridge is probably partly due to the use of the wrong boundary conditions and partly due to the limitations of the model.

(c) 1500 GMT 19 Sept., 1951

This case was chosen as typical of a slow-moving situation of early autumn (Figs. 3a-j). At 500 mb the ridge to the west of the British Isles moved only 1 or 2 degrees east in 24 hours, but the northwesterly flow over the north-eastern half of the British Isles and the North Sea was decreased to approximately half of its original strength in that time. The computed chart showed the decrease in the northwesterly flow, but moved the axis of the ridge a little too far east. The 500 mb contour height was computed to be about 300 ft higher in the Bay of Biscay than actually occurred.

The anticyclone centred at 49°N 11°W moved to the Straits of Dover in this 24-hr period with only little change of intensity, whereas the centre was computed to be in central France and the anticyclone was

/calculated

calculated to intensify. The ridge over the British Isles was computed to move into Scandinavia, and a moderate SW'ly was computed for the British Isles. In fact, the ridge only moved into the North Sea and most of the British Isles experienced light variable winds.

Since speeds of movement of several features were overestimated the computed forecast would probably be improved if the 600 mb contour heights and the 1000-600 mb thicknesses had been used instead of the 500 mb contour heights and the 1000-500 mb thicknesses.

(d) 1500 GMT 30 Jan., 1952

This situation (Figs.4a-j) was one in which the strong winds over the Atlantic at 500 mb associated with a jet stream at higher levels spread south-eastwards to affect the south-western sea-board of Europe throughout the ensuing 24 hours. The 12-hr computed forecast was quite reasonable, but subsequently the strong winds were computed to extend across the North Sea. The 500 mb vortex was also computed to move in its entirety to the Faroes, but this did not happen. The computed winds were stronger than those that actually occurred, which was partly due to the incorrect treatment of the 500 mb vortex, and partly due to the fact that the height of the 500 mb contour along the 50°N parallel was forecast to increase whereas it actually decreased in the region of the British Isles. The effect of the western boundary may have spread further into the chart than usual as a result of the exceptionally strong winds.

The behaviour of the 1000 mb depression was more accurately dealt with, but the main frontal trough was computed much further east than actually occurred. There are signs of the beginnings of computational instability in the computed charts, especially the thickness and 1000 mb charts. This is not surprising considering the exceptionally strong winds.

The computed thickness chart for 1500 GMT 31 Jan. gave the main thickness trough too far north-east, and most of the absolute values of thickness over the sea were too low. This forecast could probably be improved by taking into account the effect of the warming of cold air masses over the sea, and also by using the flow at 600 mb instead of 500 mb.

(e) 1500 GMT 13 May, 1952

The computed charts for the 24-hr period commencing 1500 GMT 13 May, 1952 agree quite well with the actual charts (Figs. 5a-j). During this period only slight changes occurred. The 500 mb flow over the British Isles was correctly computed to be displaced northwards and intensified, but the absolute values of the computed 500 mb contour height for 1500 GMT 14 May were about 200 ft too high.

The computed 1000 mb charts agree quite well with actuality in the vicinity of the British Isles, but slight errors in both the computed contour height and thickness in the vicinity of the mid-Atlantic surface depression have caused the computations to indicate the north-northeastwards motion of that depression, whereas it actually drifted slowly eastwards.

(f) 1500 GMT 3 July, 1952

This was another situation in which the computed charts agree quite well with the actual charts in the region of the British Isles. A cut-off depression at 500 mb, together with an associated cold pool, developed during the period. The computed charts indicated this, although in each case the centre was too far east. The absolute values of the highest regions of the computed 500 mb contour chart for 1500 GMT 4 July were again about 200 ft too high, and the area SE of Greenland was incorrectly dealt with due to considerable changes on the boundary which were ignored.

/(g)

(g) 1500 GMT 31 Dec., 1952

At the commencement of this forecast period the flow over Western Europe and the North Atlantic was largely meridional at all levels in the troposphere, there being a deep 500 mb trough over Labrador and another over the western seaboard of Europe with a cut-off low over England and the North Sea. During the ensuing twenty-four hours there was slow progession in fairly high latitudes, the Atlantic ridge moving in towards the British Isles and the cut-off 500 mb low moving southwards over France. The accompanying surface low moved from the North Sea to northern Italy.

These main trends were well forecast by computational methods, but minor surface cyclonic activity moved into the forecast area from south of Labrador and was therefore not forecast. In association with this error the surface anticyclone and warm ridge south of Iceland were computed to develop too strongly.

(h) 1500 GMT 30 Jan., 1953

This was the occasion of the disastrous flooding in the Netherlands and along the east coast of England. At 1500 GMT on the 30th the centre of the depression which caused the floods was over the Faroes, the main warm front over southern Norway and the Kattegat, a secondary warm front over Ireland and the cold front approaching the western coasts of Scotland and Ireland. During the forecast period the depression moved south-eastwards to the Skegerrak, the cold front and secondary warm front amalgamated to give an occlusion over Eastern Germany and a surface trough formed in the cold air over the North Sea. Meanwhile the anticyclone south-east of Greenland developed and moved eastwards to a position south of Iceland.

The depression was computed to move eastwards to the Norwegian coast with troughs in the correct places over Germany and the North Sea. However, the anticyclonic development in the Western Approaches was over-estimated by the computations giving a very strong north-northwesterly gradient over the British Isles at all levels in the troposphere. In association with this very deep cold air was forecast to be advected across the British Isles from the Iceland region. These effects combine to give the forecast charts shown in Figs. 8h and 8j. There is no doubt that if these charts had been correct the floods would have been even more calamitous than they actually were. These errors were due to a number of causes including the considerable surface friction which would be associated with such high winds, the warming of the deep cold air as it passed over the warm sea near the British Isles and the over-estimation of anticyclonic development which appears inherent in the present model. It will be noticed from the table of correlation coefficients that despite these errors the computed forecasts were of a similar standard to those produced by conventional methods.

(i) 1500 GMT 18 July, 1953

During the forecast period a large but shallow low pressure area centred near the Shetlands moved north-eastwards into central Norway and a ridge moved in from the Atlantic over the British Isles. During this time the 500 mb low over the British Isles was also replaced by a ridge and a 1000-500 mb thickness trough moved from Ireland to the North Sea. These considerable changes near the British Isles were well forecast both by conventional and numerical methods. However, the computed forecast was not quite so successful over the Atlantic. A depression which was south-east of Greenland at the beginning of the forecast period moved eastwards and at the end of the twenty-four hours the warm front was approaching south-western Ireland. Although a considerable trough was computed to move eastwards with a similar speed to the actual frontal

/trough

trough, the depression itself was computed to deepen and remain stationary. This error appears to be due to the fact that at present the computational forecast does not allow motion across the western boundary, and in this case, as in several others, such motion actually occurred.

(j) 1500 GMT 15 Oct., 1953

The charts on which the forecast was based show a deep depression south-east of Greenland with a frontal trough at about 15°W. There are anticyclones to the west of the Azores and over Scandinavia and a shallow low pressure area covers most of the rest of Europe. In the 1000-500 mb thickness pattern there is a deep cold trough behind the Atlantic depression, a small ridge to the west of the British Isles and a cut-off cold pool over the Western Mediterranean. Both computed and conventional forecasts correctly brought the frontal trough and thermal gradient in over Ireland but kept the main centre back south-west of Iceland. Over Europe, however, the computed forecasts suffered from an error due to an unusual cause. Both 500 mb contour and 1000-500 mb thickness charts for the beginning of the period show a strong southerly jet-stream in the region of Algeria to the east of a cut-off low. Since this region is close to both the southern and eastern boundaries of the computed charts, this jet-stream was assumed to be maintained and the consequent advection of cyclonic vorticity on its western flank was computed to give rise to a small but intense 500 mb low over Germany and an accompanying surface depression over the Low Countries.

4. Comparison of computed and conventional forecasts

Correlation coefficients between the computed and actual 24-hr changes of contour height and thickness and regression coefficients a and b of the best fitting straight line giving the actual change (Y tens of feet) in terms of the computed change (X tens of feet) in the form

$$Y = a X + b \qquad (3)$$

were calculated for the interior grid of 12 x 8 points.

TABLE I

CORRELATION AND REGRESSION COEFFICIENTS

Starting Date	Method	500 mb			1000-500 mb			1000 mb (A) and Surface Pressure (B)		
		r	a	b	r	a	b	r	a	b
8. 1.51	A	0.68	0.63	13.2	0.59	0.81	19.8	-0.27	-0.18	- 2.2
	B	0.61	0.71	2.3	0.82	1.02	-0.1	0.59	0.75	- 1.5
10. 8.51	A	0.90	0.69	-10.2	0.84	0.75	-5.4	0.85	0.58	- 0.7
	B	0.87	1.23	- 4.2	0.91	1.32	-4.4	0.87	1.15	- 1.5
19. 9.51	A	0.89	0.83	-12.5	0.47	0.43	-3.3	0.72	0.53	- 5.6
	B	0.74	0.89	- 2.9	0.22	0.21	-0.4	0.86	0.81	- 0.6
30. 1.52	A	0.61	0.36	25.3	0.58	0.33	-3.3	0.52	0.51	21.7
	B	0.67	0.62	-16.7	0.86	0.69	-4.6	0.79	0.92	- 1.6
13. 5.52	A	0.87	0.56	- 8.8	0.85	0.62	3.7	0.35	0.15	- 5.3
	B	0.94	0.85	- 2.1	0.92	1.02	1.5	0.67	0.66	- 2.2
3. 7.52	A	0.48	0.87	- 8.3	0.46	0.68	-7.7	0.27	0.19	0.2
	B	0.87	0.99	- 7.0	0.74	1.04	3.9	0.36	0.31	1.7
31.12.52	A	0.46	0.43	- 5.9	0.08	0.06	-2.6	0.55	0.51	- 6.5
	B	0.79	1.00	- 9.0	0.57	0.66	0.2	0.79	1.09	- 5.8
30. 1.53	A	0.96	0.75	-12.3	0.89	0.56	1.2	0.88	0.62	-15.5
	B	0.90	1.10	21.3	0.86	1.03	7.5	0.91	1.09	- 1.2
18. 7.53	A	0.78	0.79	- 3.9	0.93	1.01	0.7	0.67	0.55	- 3.6
	B	0.91	1.04	5.9	0.89	1.14	7.7	0.89	0.79	1.4
15.10.53	A	0.64	0.62	24.1	0.75	0.81	2.1	0.73	0.39	22.4
	B	0.90	1.10	9.1	0.85	1.38	-5.4	0.73	0.59	6.5

r = correlation coefficient, A = computed forecast,
B = conventional forecast, heights in tens of feet, pressures in mb

/The

The conventional forecasts prepared by the Forecast Branch of the Meteorological Office, Dunstable, do not cover exactly the same period as the computed charts, but a similar set of values comparing the conventional forecast changes with the actual changes is also shown in Table I, using the conventional forecast which related as closely as possible to the period covered by the computations.

The grid of 12 x 8 points was used in order to decrease the effect of boundary conditions on the correlation coefficients. However, large pressure changes in mid-Atlantic due to the eastward movement of large atmospheric systems across the western boundary can cause large errors in the computed charts at some of the 12 x 8 grid points. As these changes are often of greater magnitude than those in the vicinity of the British Isles, the correlation between the computed and actual changes is lower than it otherwise would be. This was particularly noticeable for the two situations of 8 Jan., 1951 and 3 May, 1952. The computed and conventional forecast charts were quite similar in the region of the British Isles but there was a considerable difference in the correlation coefficients due to the conventional forecaster correctly estimating large changes in mid-Atlantic. Another limitation of the correlation method of comparing forecasts is the fact that in a situation of little change, a small error in the position of a depression may have a considerable effect on the correlation coefficient. A similar adverse effect is caused by any large forecast change which is correct in magnitude, but in error in position. Nevertheless, Table I does give some indication of the degree of success of the computed forecast compared with that of the conventional forecast for the interior grid of 96 points.

5. Conclusion

The main conclusion for the present series of calculations is that the Sawyer-Bushby two-parameter model has achieved an encouraging amount of success away from the boundary in nine of the ten situations that were examined. In five of these the computed forecasts for the vicinity of the British Isles were of the same standard as those prepared by conventional methods, but in the other four situations conventional methods produced a somewhat better forecast than the computations.

The discrepancies between the actual and computed charts were examined in an attempt to decide if any aspect was common to more than one of the computations. It is immediately apparent that in winter months, the computed thickness over the sea is often much less than it actually was and this is almost certainly due to the neglect of the heating of cold air masses over the sea in the basic equations.

Another common discrepancy is the over-estimation of the absolute value of the contour heights in anticyclonic regions. The reason for this is not immediately apparent, but in the theory of the method the parameters h_m and h' are treated more as stream functions than as contour heights, and as the geostrophic vorticity is an underestimate in anticyclonic regions, the use of the geostrophic approximation to obtain a contour height from the computed vorticity field could give rise to this type of error. The reason why the cyclonic developments are dealt with more accurately could be that in cyclonic regions errors due to the neglect of friction and to the use of the geostrophic approximation tend to cancel out, whereas they do not in anticyclonic regions.

In certain of the situations where the mobility was computed to be more than actually occurred, this may have been due to the use of the 500 mb contour heights and the 1000-500 mb thicknesses instead of the 600 mb contour heights and the 1000-600 mb thicknesses to which the theoretical equations were designed to apply.

Finally, it is quite apparent that the present size of the 18 x 14 grid is a bare minimum if reasonably correct forecasts are to be produced for the British Isles.

/Further

Further investigation will be needed to ascertain how far the standard of the computed charts can be improved by reducing the aforementioned limitations on the model, but the success so far achieved with the crude two-parameter model is sufficient to encourage the belief that further progress forward from this stage can be made.

References

Bushby, F.H. and Hinds, M.K.	1954	Quart. J. R. Met. Soc., 80 (in press).
Sawyer, J.S. and Bushby, F.H.	1953	J. Met., 10, p.54.

G.401483/JWP/5/54/40.

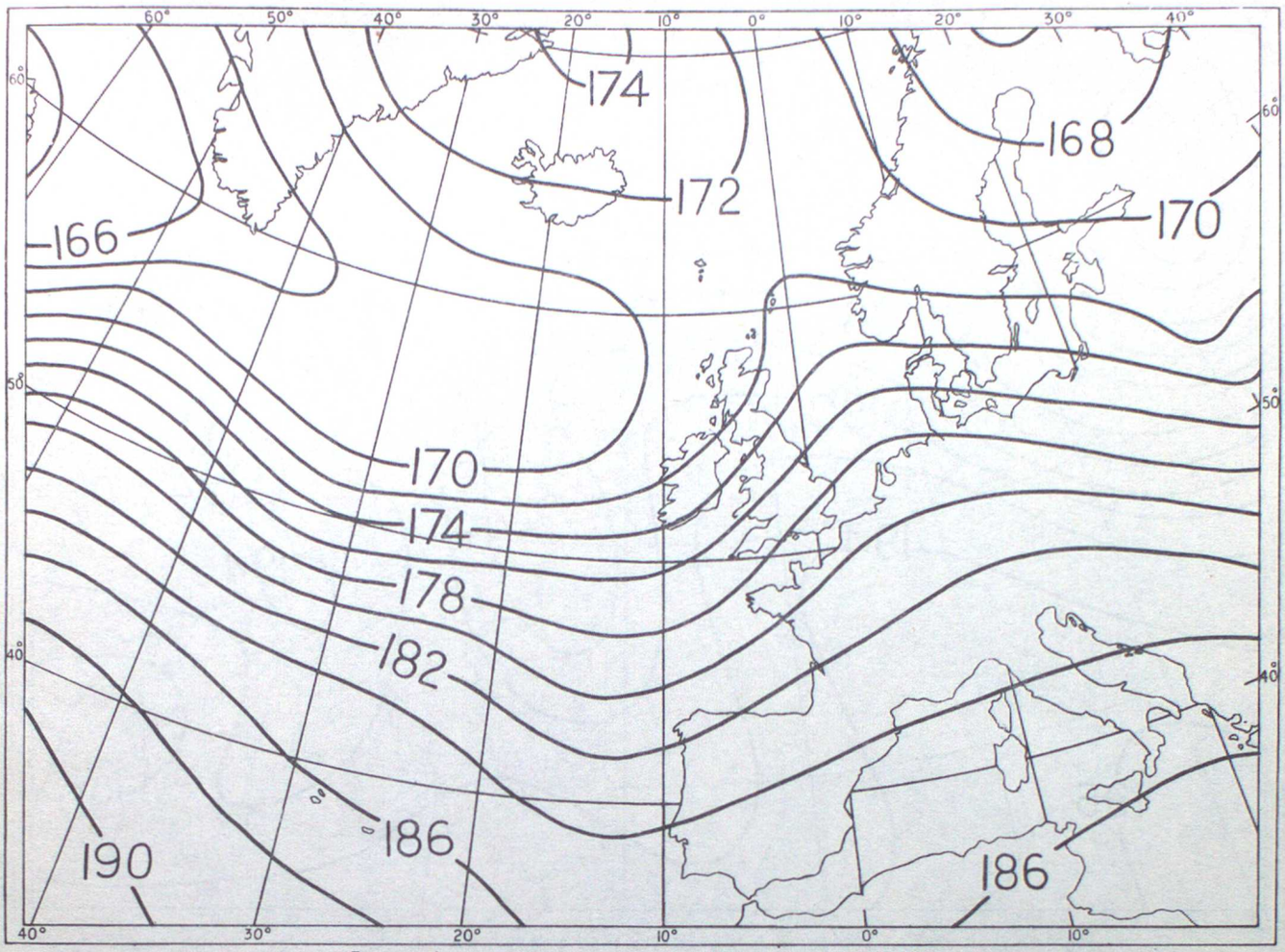

Fig 1(a) Actual 500 mb. contour chart for 1500 G.M.T. 8.1.51

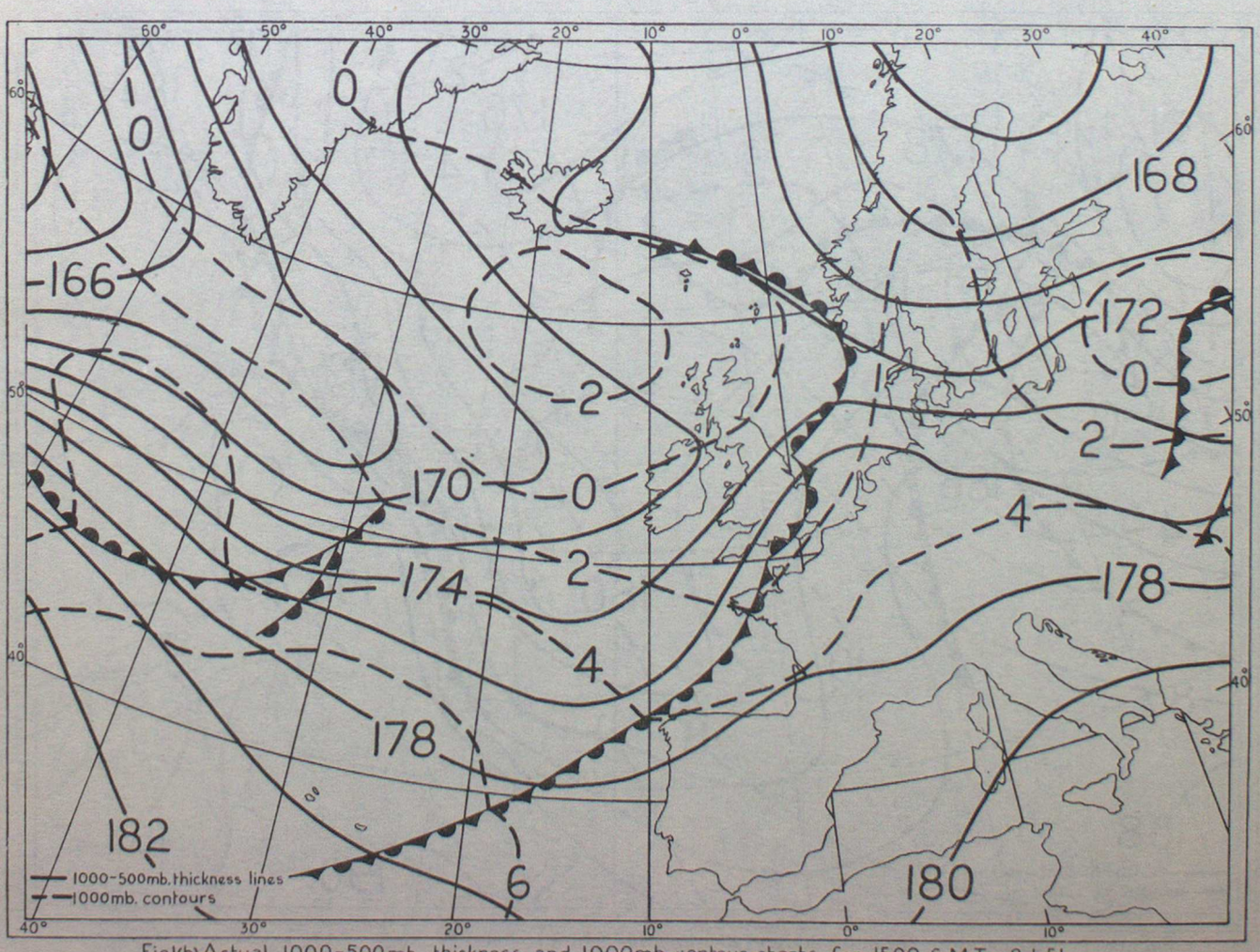

Fig 1(b) Actual 1000-500 mb. thickness and 1000 mb. contour charts for 1500 G.M.T. 8.1.51

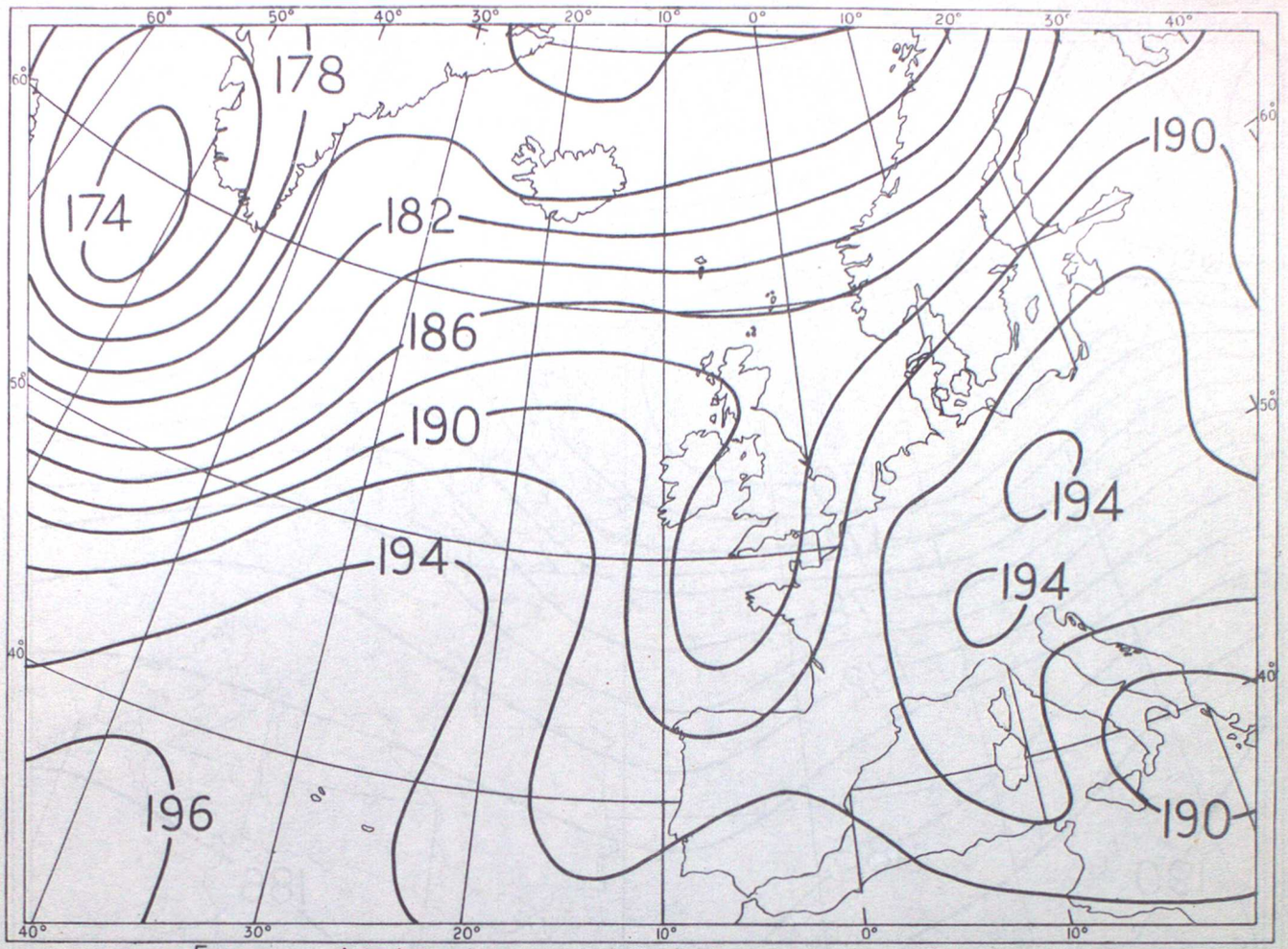

Fig.6(a) Actual 500mb. contour chart for 1500 G.M.T. 3.7.52

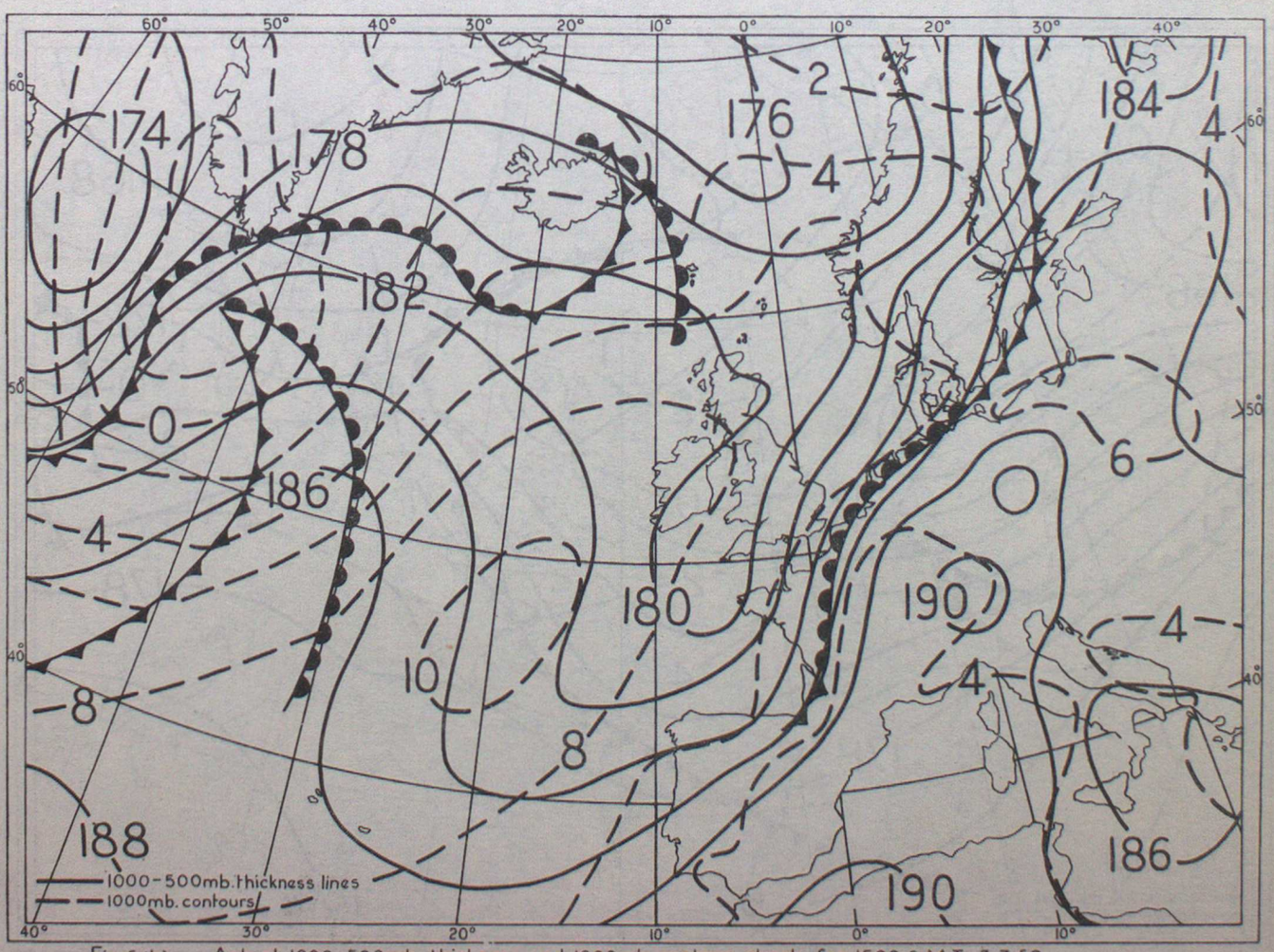

Fig.6(b) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 3.7.52

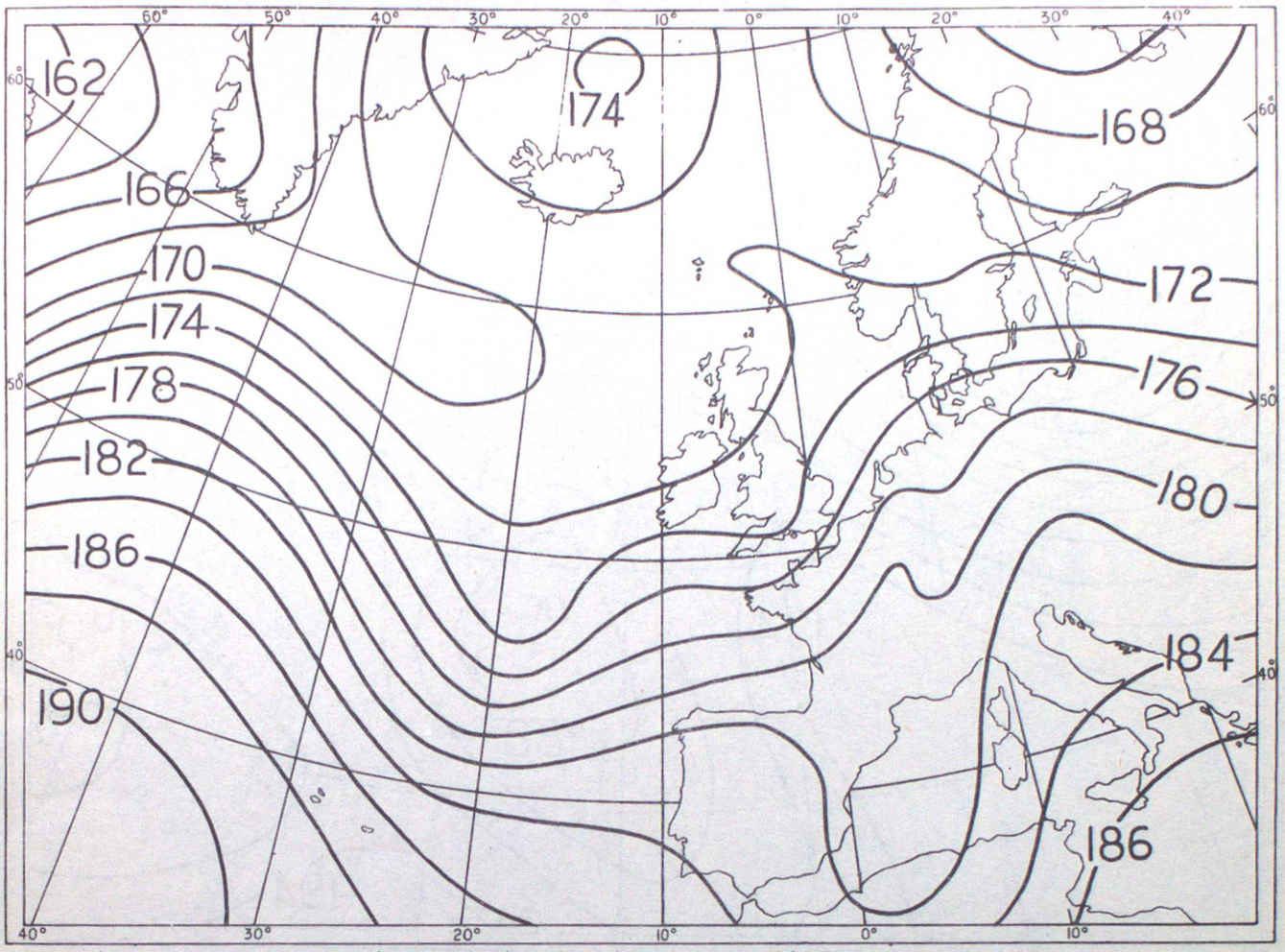

Fig1(c) Actual 500mb. contour chart for 0300 G.M.T. 9.1.51

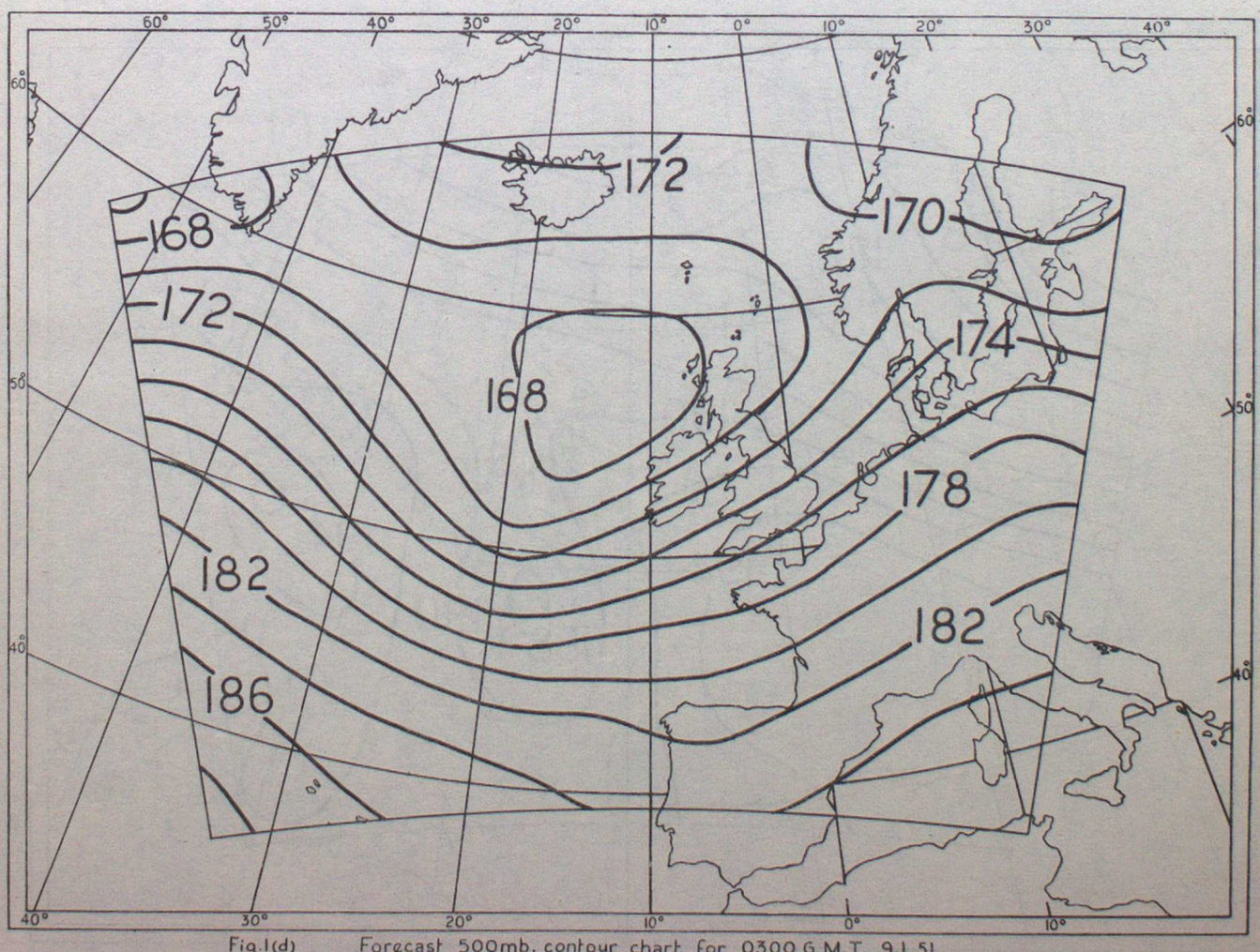

Fig.1(d) Forecast 500mb. contour chart for 0300 G.M.T. 9.1.51

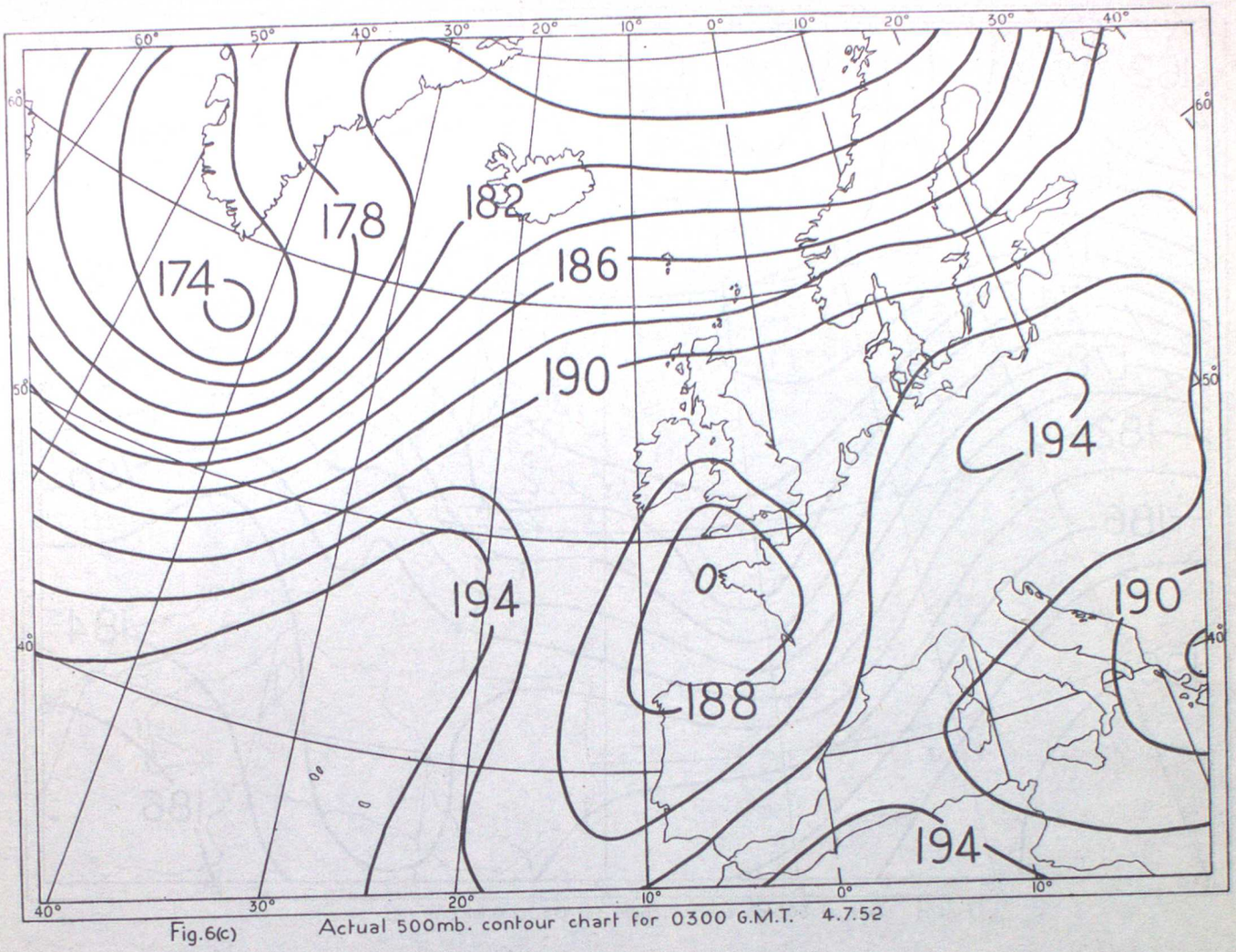

Fig.6(c) Actual 500mb. contour chart for 0300 G.M.T. 4.7.52

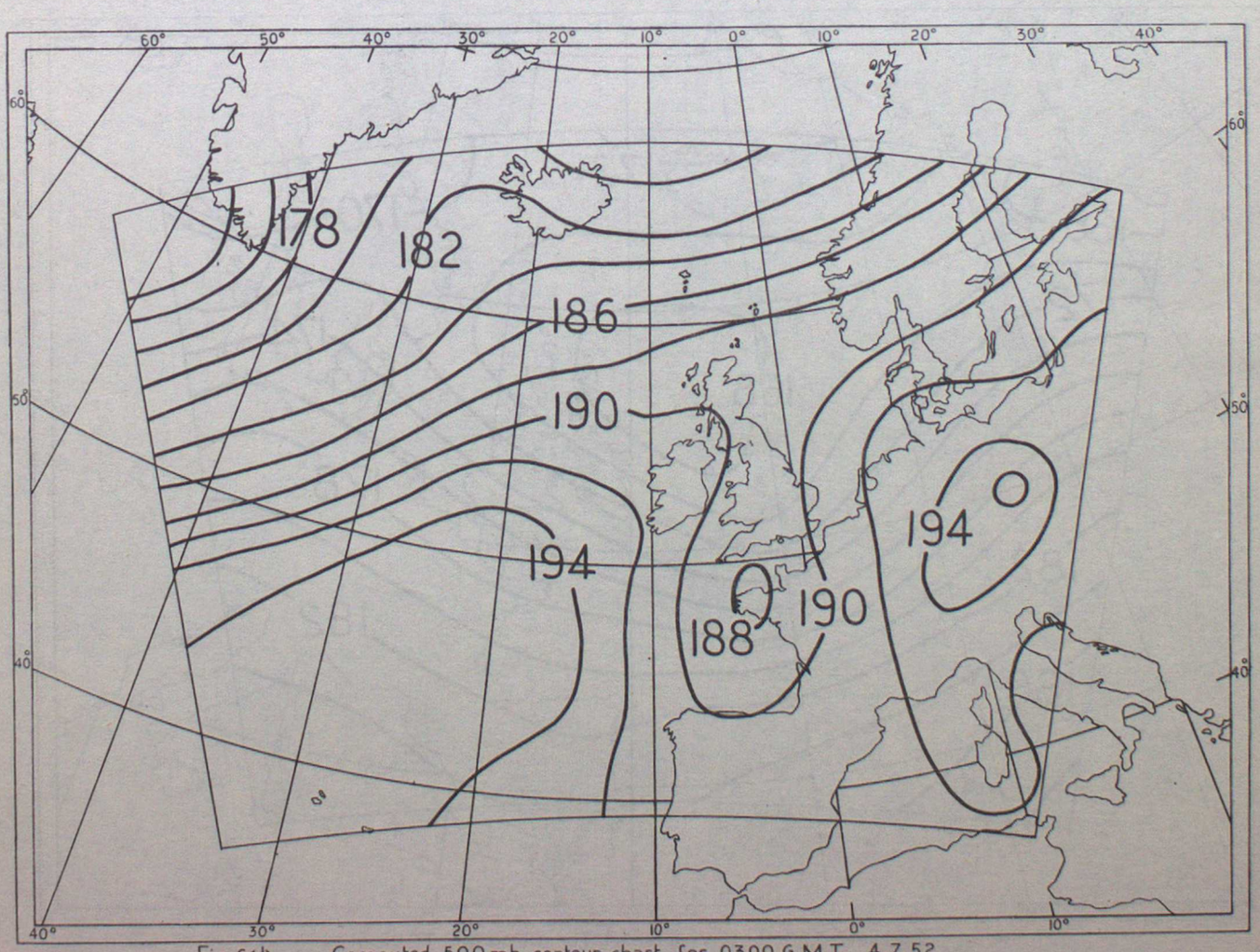

Fig.6(d) Computed 500 mb. contour chart for 0300 G.M.T. 4.7.52

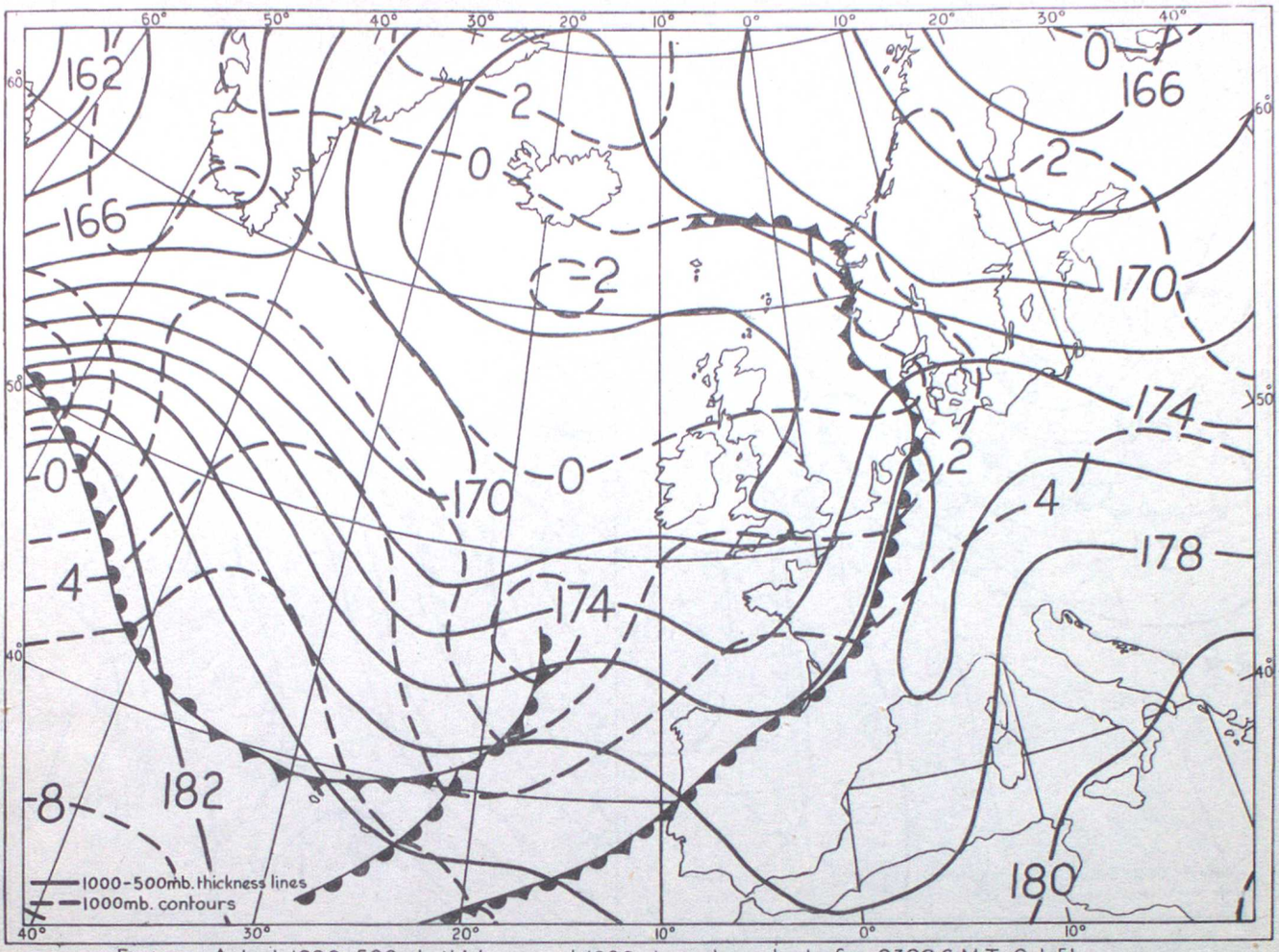

Fig.1(e) Actual 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 9.1.51

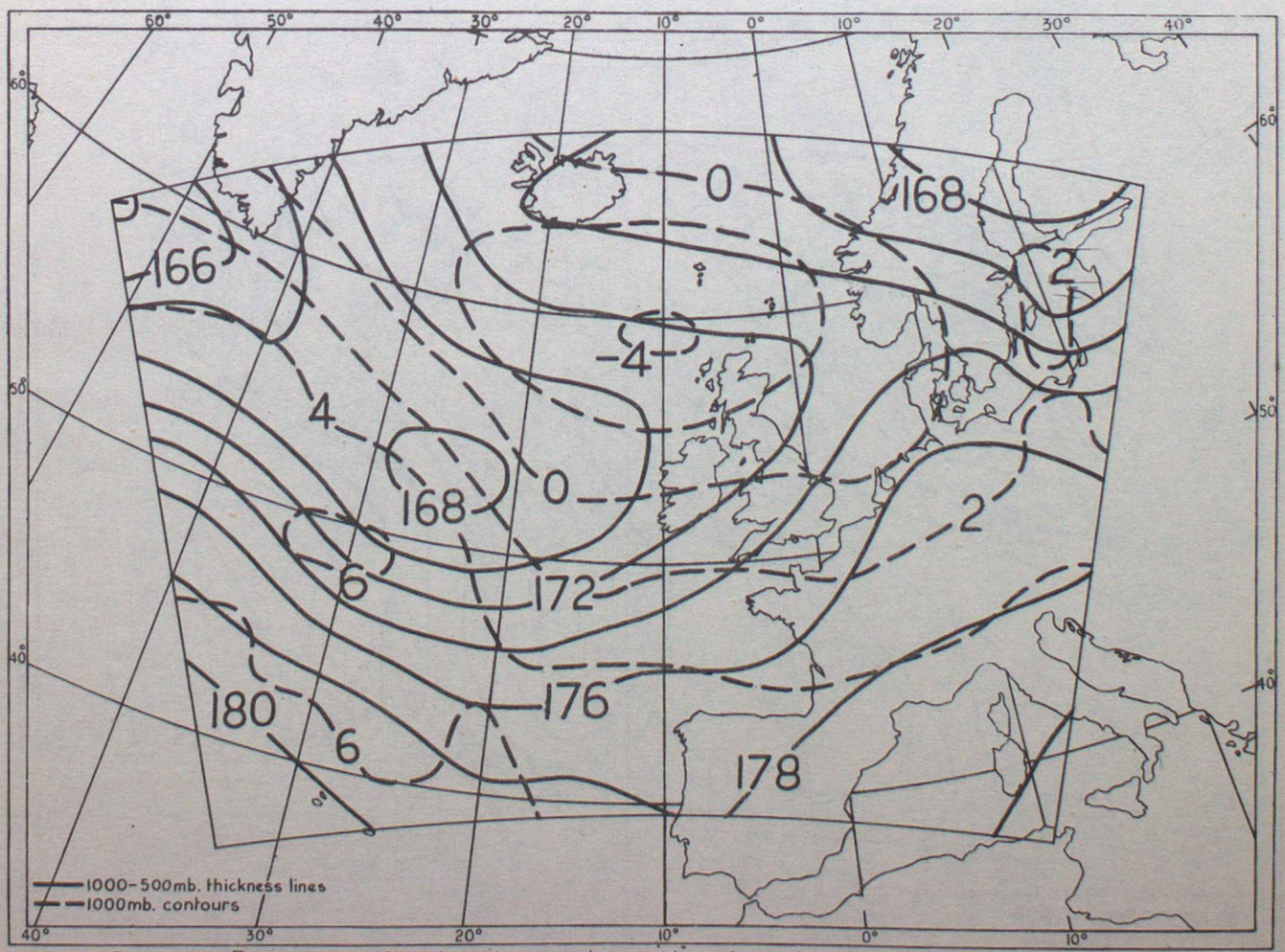

Fig.1(f) Forecast 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T 9.1.51

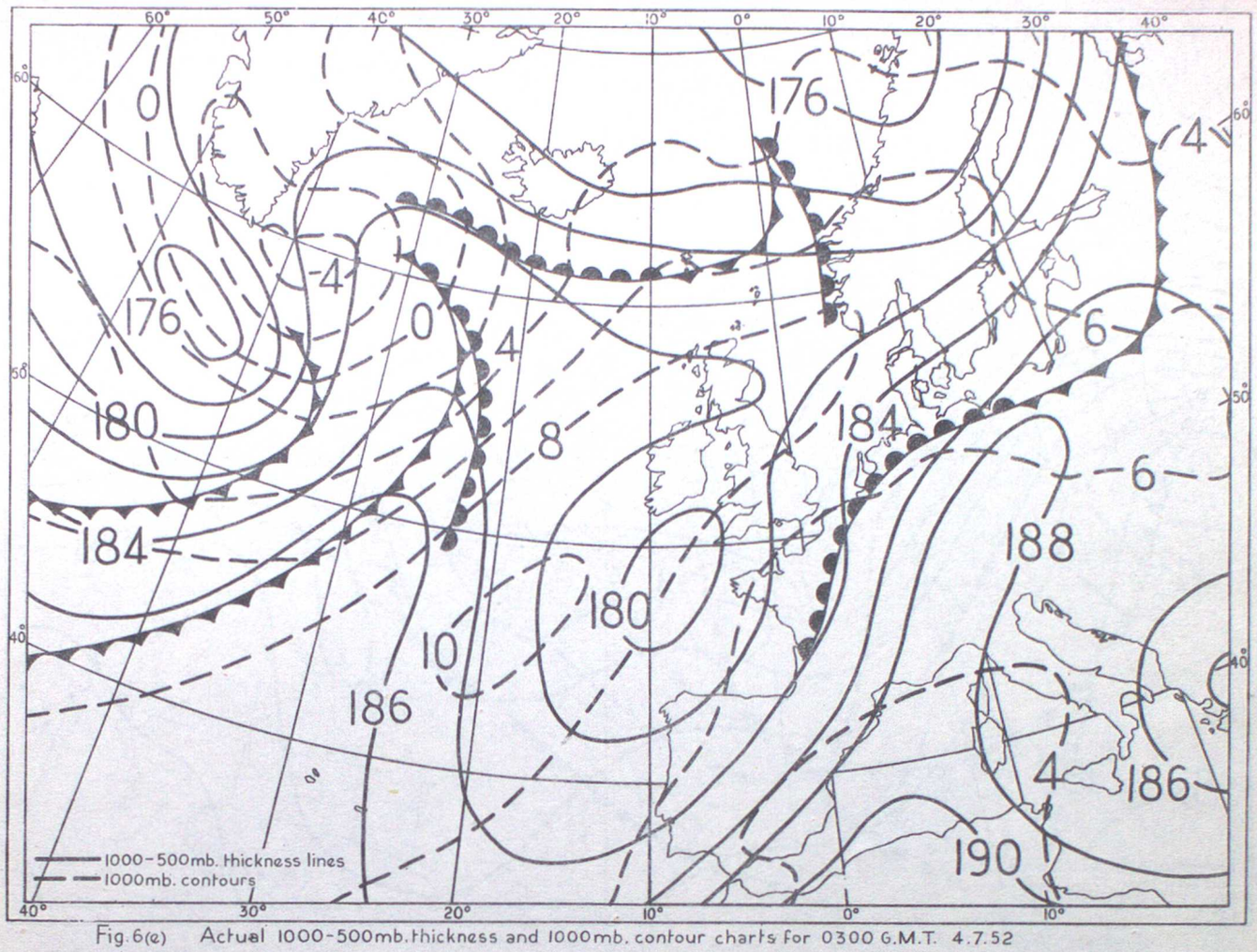

Fig.6(e) Actual 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 4.7.52

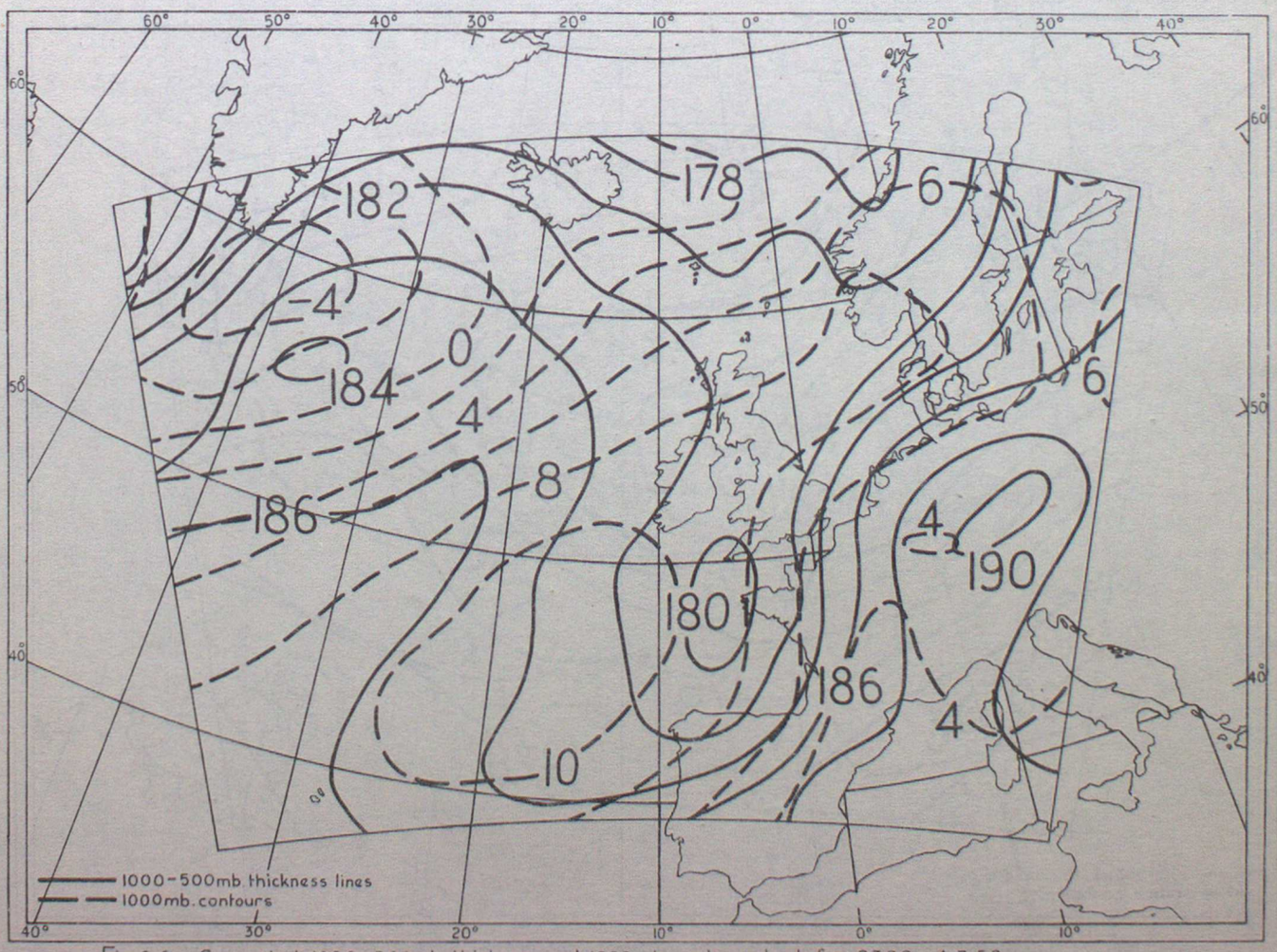

Fig.6(f) Computed 1000-500mb. thickness and 1000mb. contour charts for 0300 4.7.52

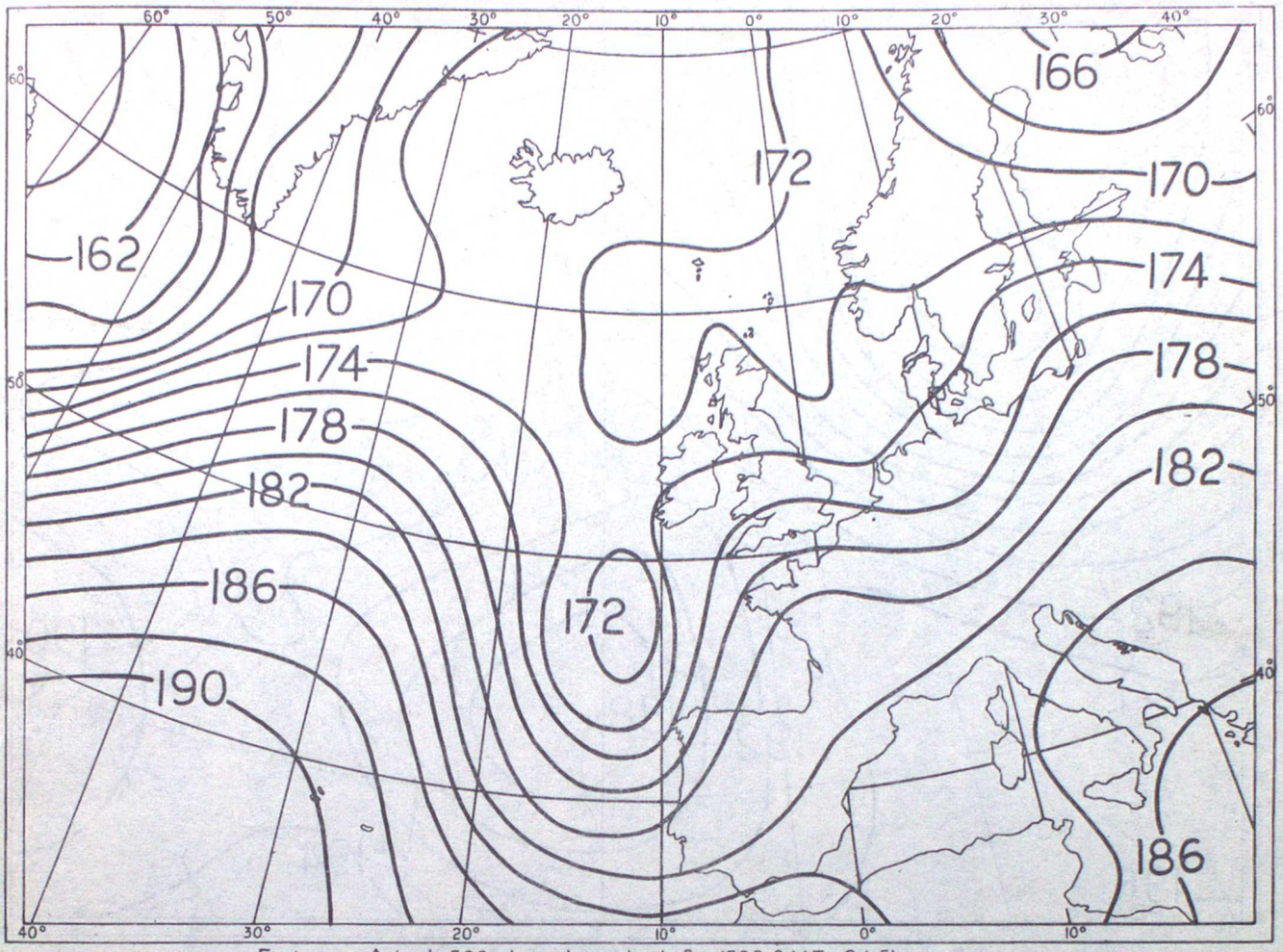

Fig.1(g) Actual 500mb. contour chart for 1500 G.M.T. 9.1.51

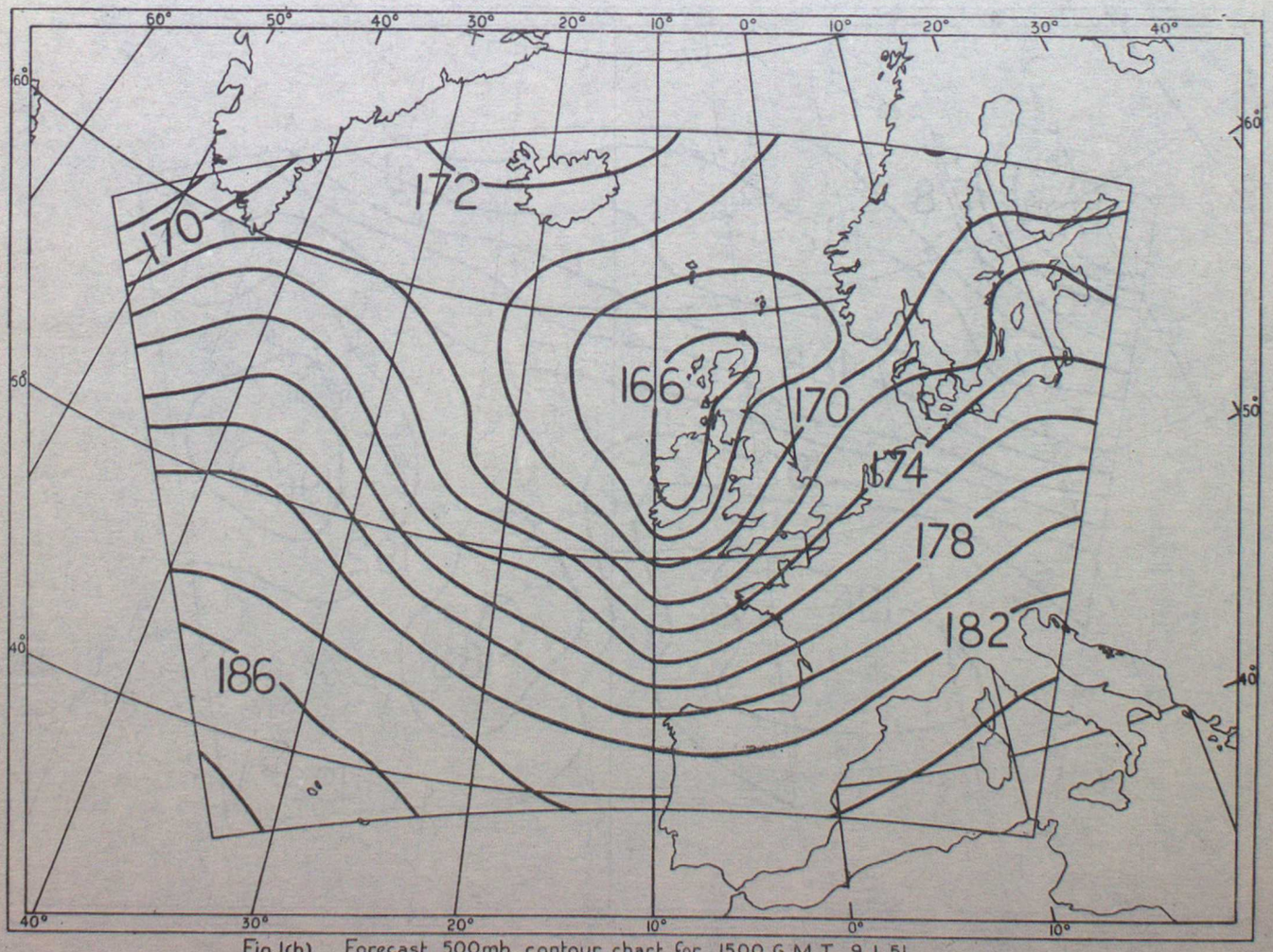

Fig.1(h) Forecast 500mb. contour chart for 1500 G.M.T. 9.1.51

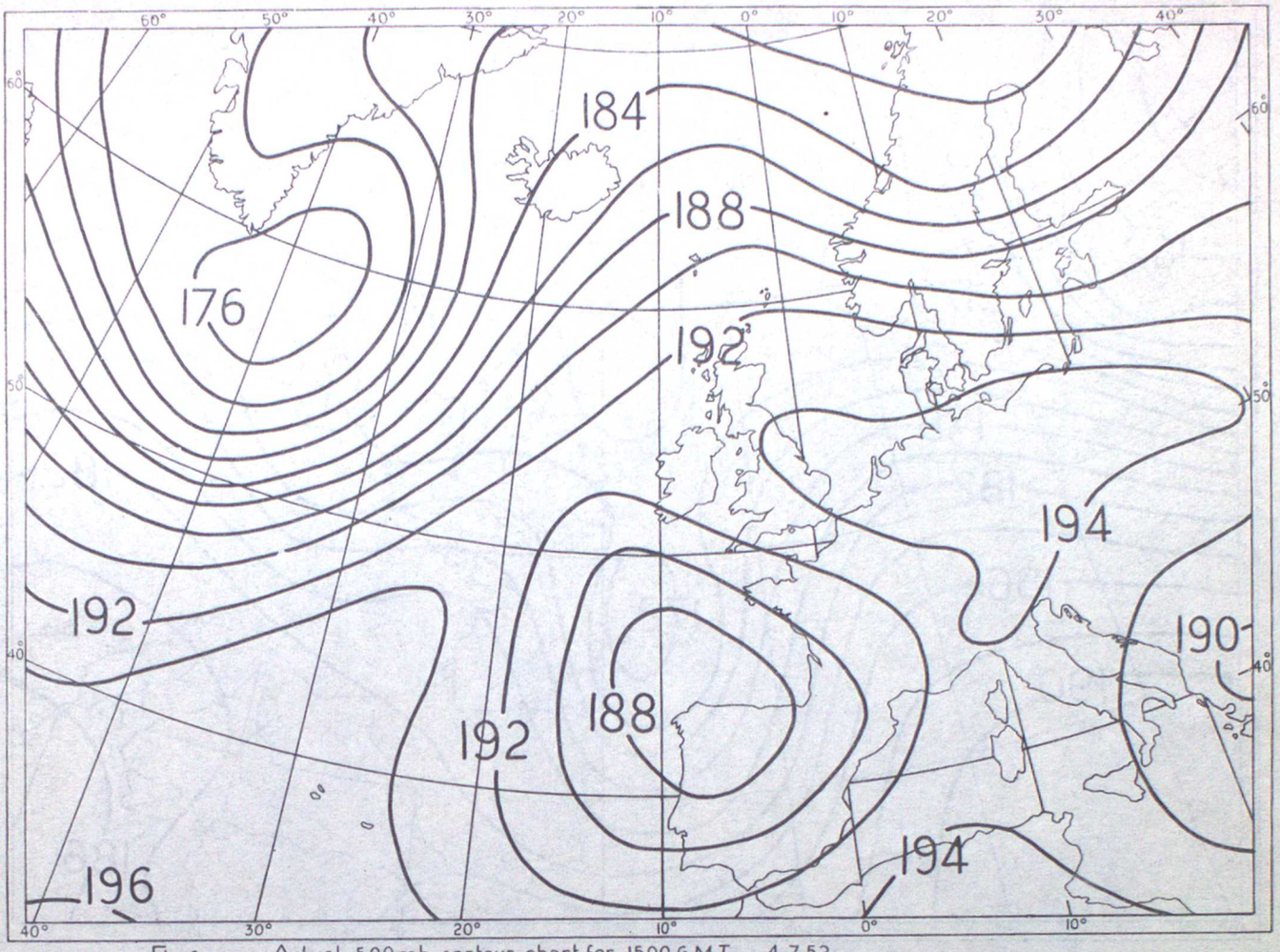

Fig.6(g) Actual 500mb. contour chart for 1500 G.M.T. 4.7.52

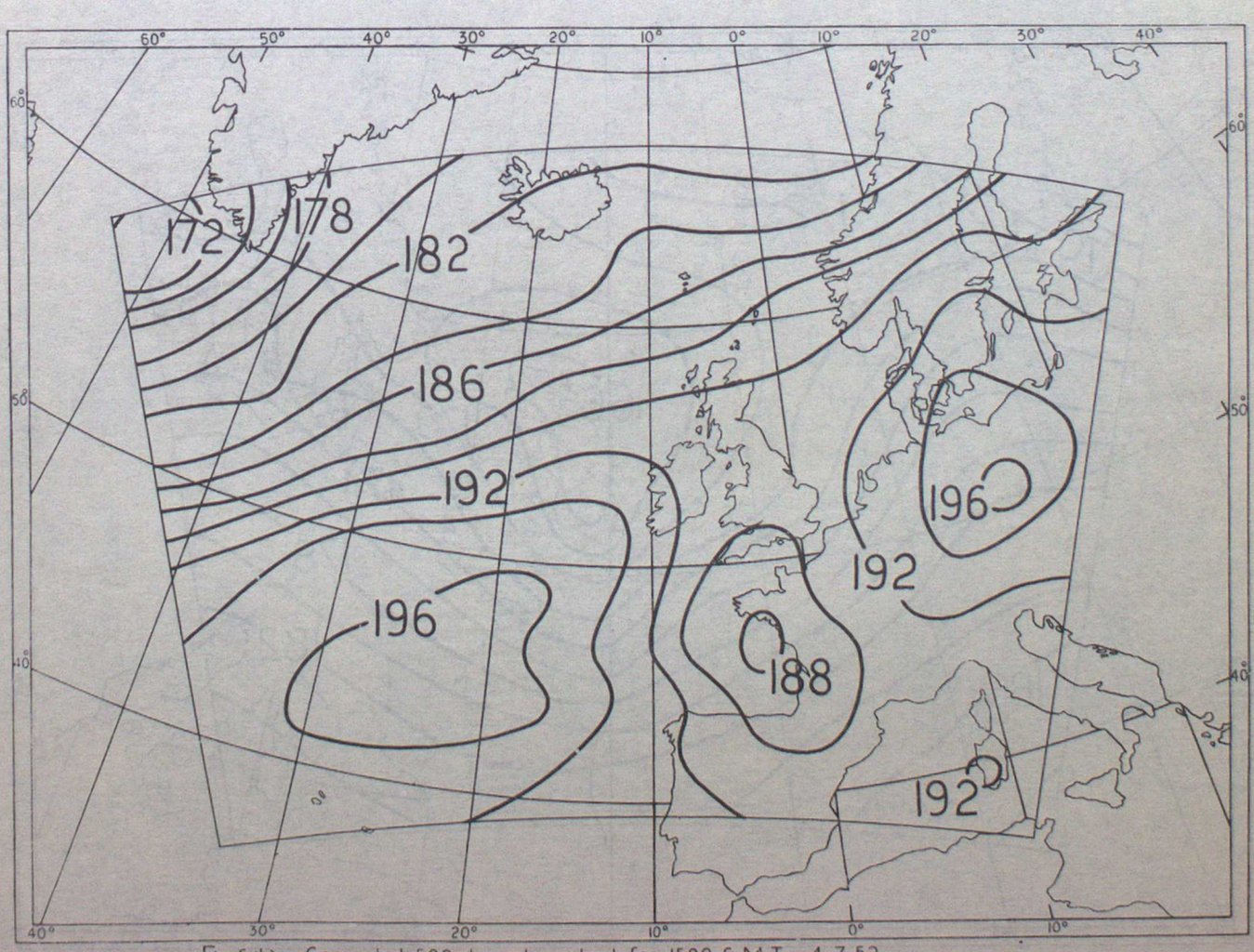

Fig.6(h) Computed 500mb contour chart for 1500 G.M.T. 4.7.52

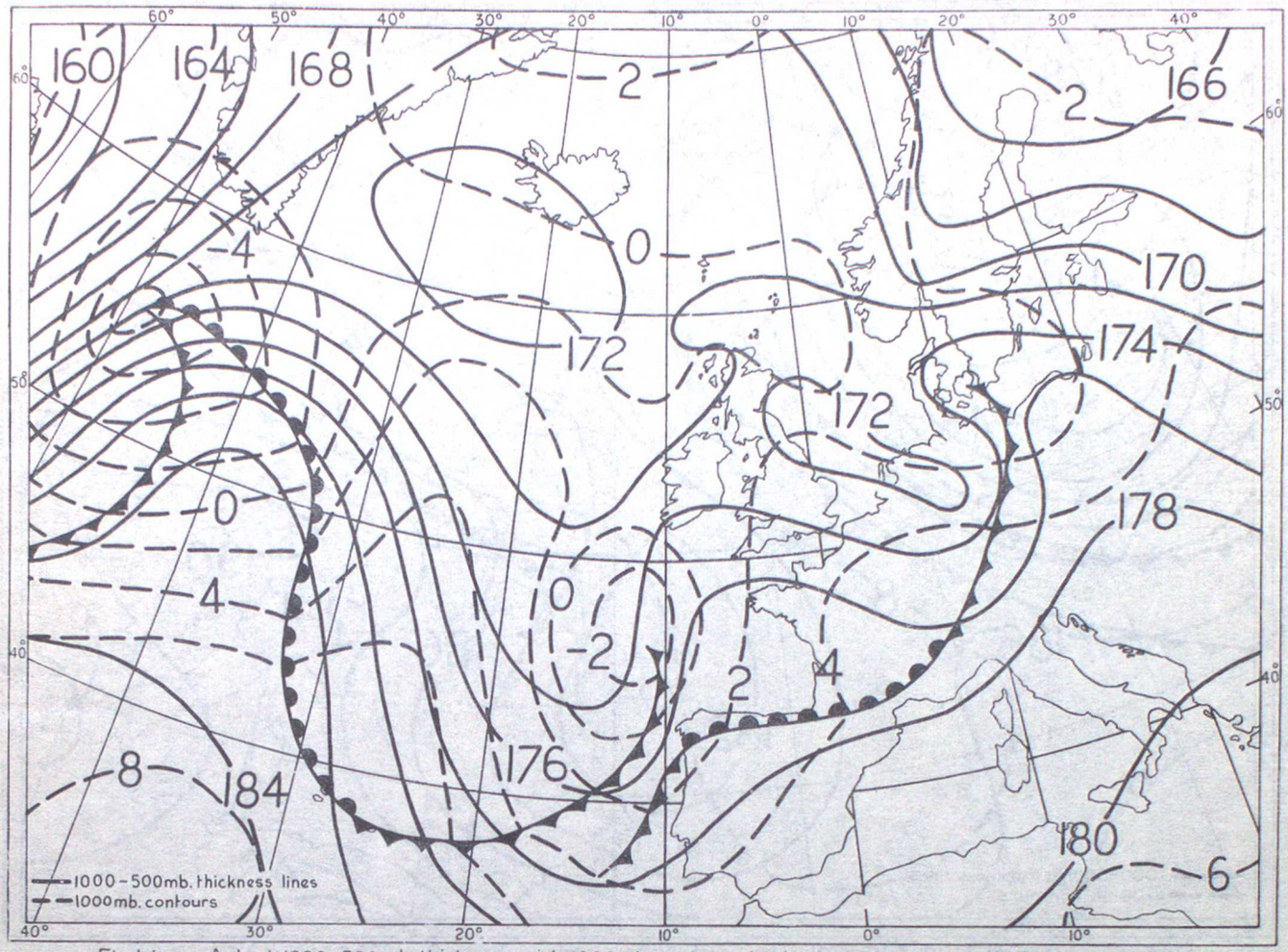

Fig.1(i) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 9.1.51

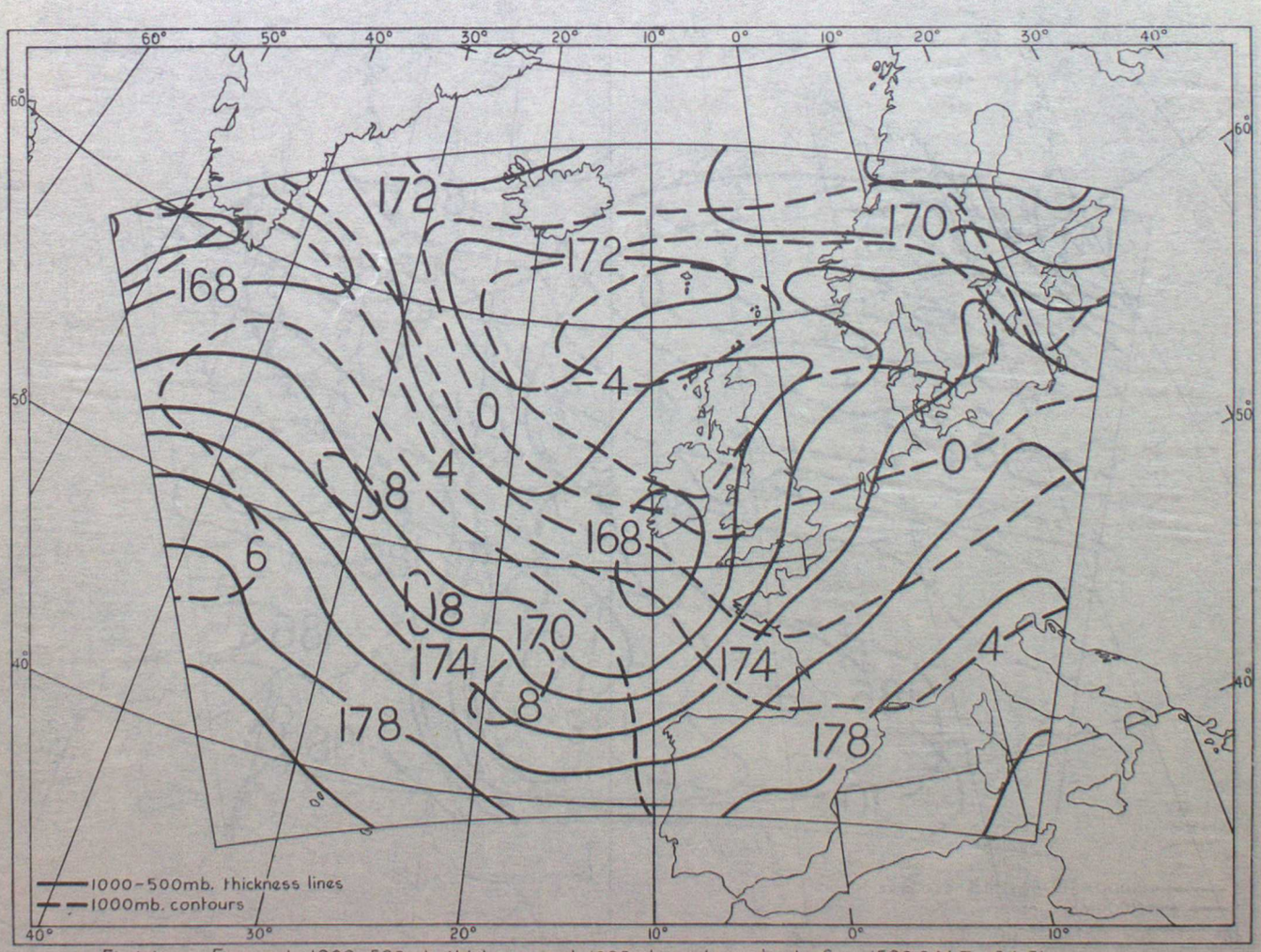

Fig.1(j) Forecast 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 9.1.51

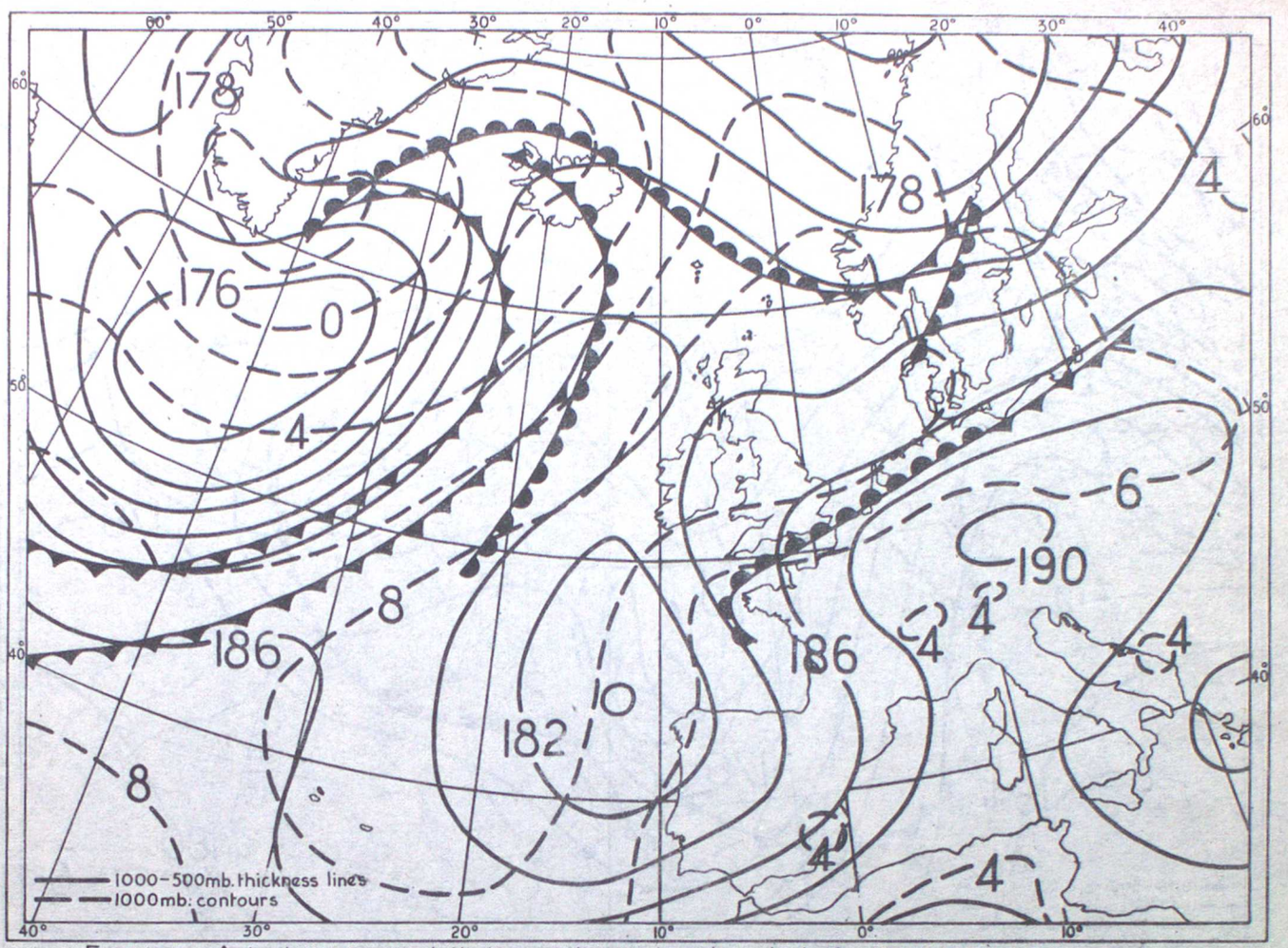

Fig.6(i) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 4.7.52

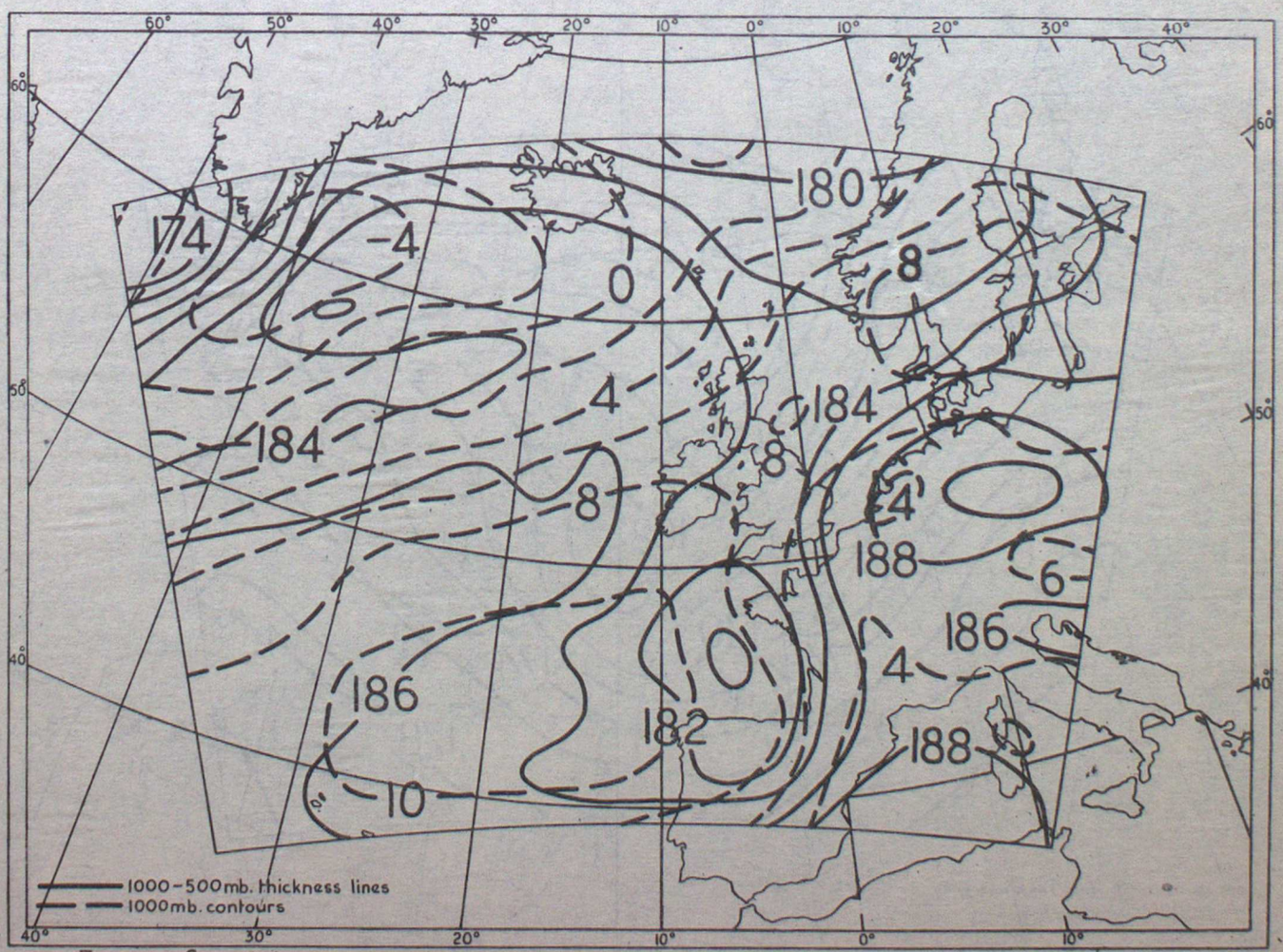

Fig.6(j) Computed 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 4.7.52

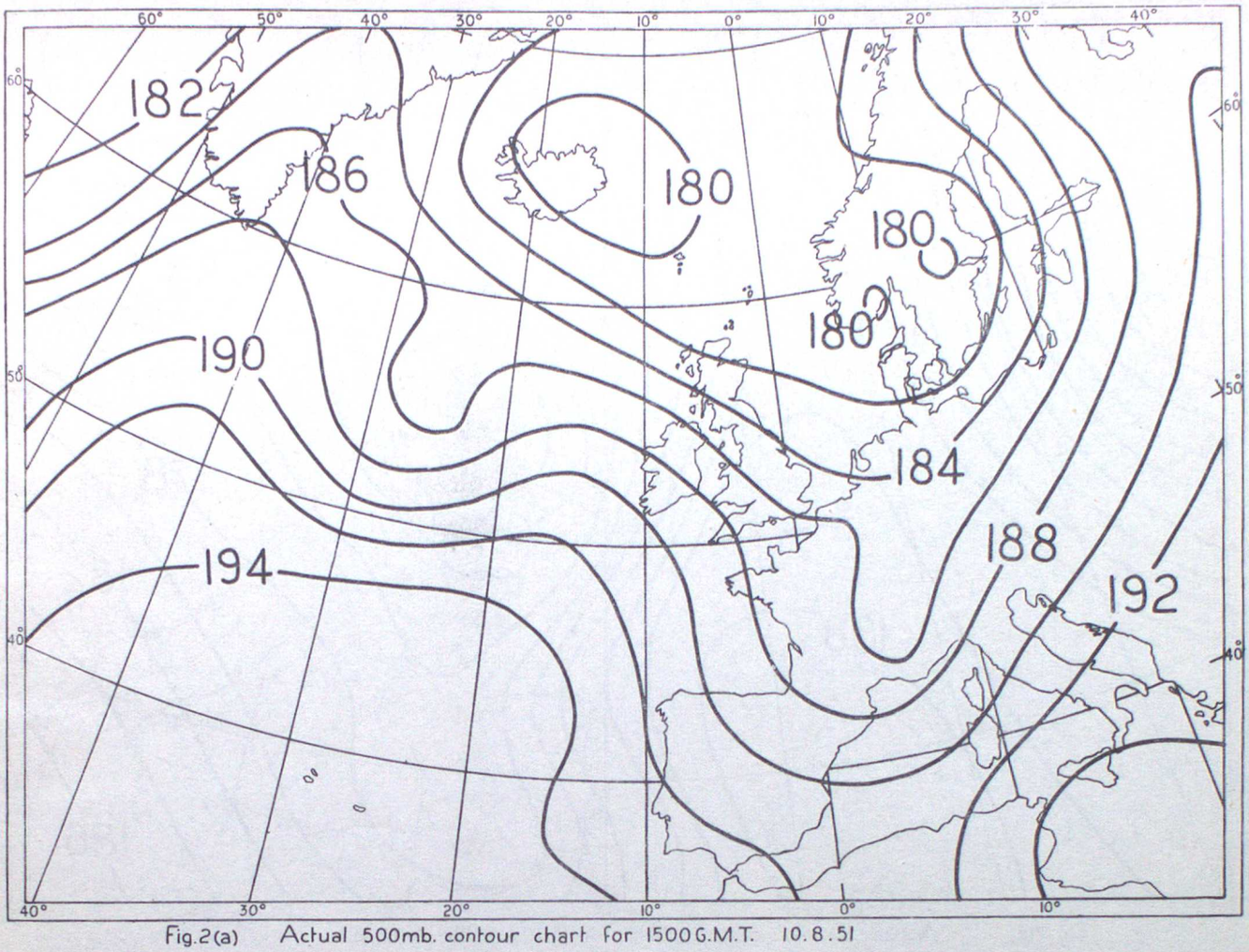

Fig.2(a) Actual 500mb. contour chart for 1500 G.M.T. 10.8.51

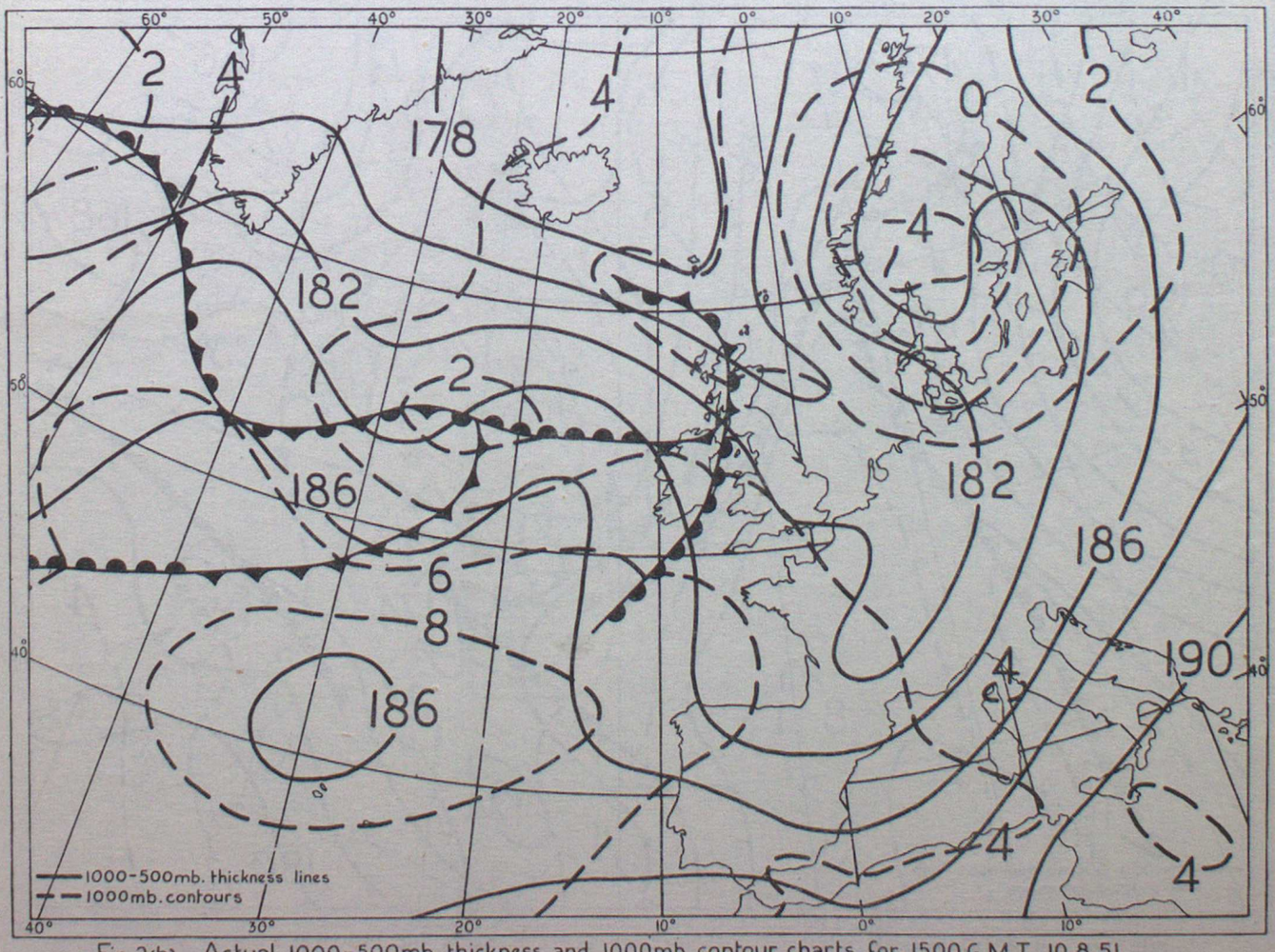

Fig.2(b) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 10.8.51

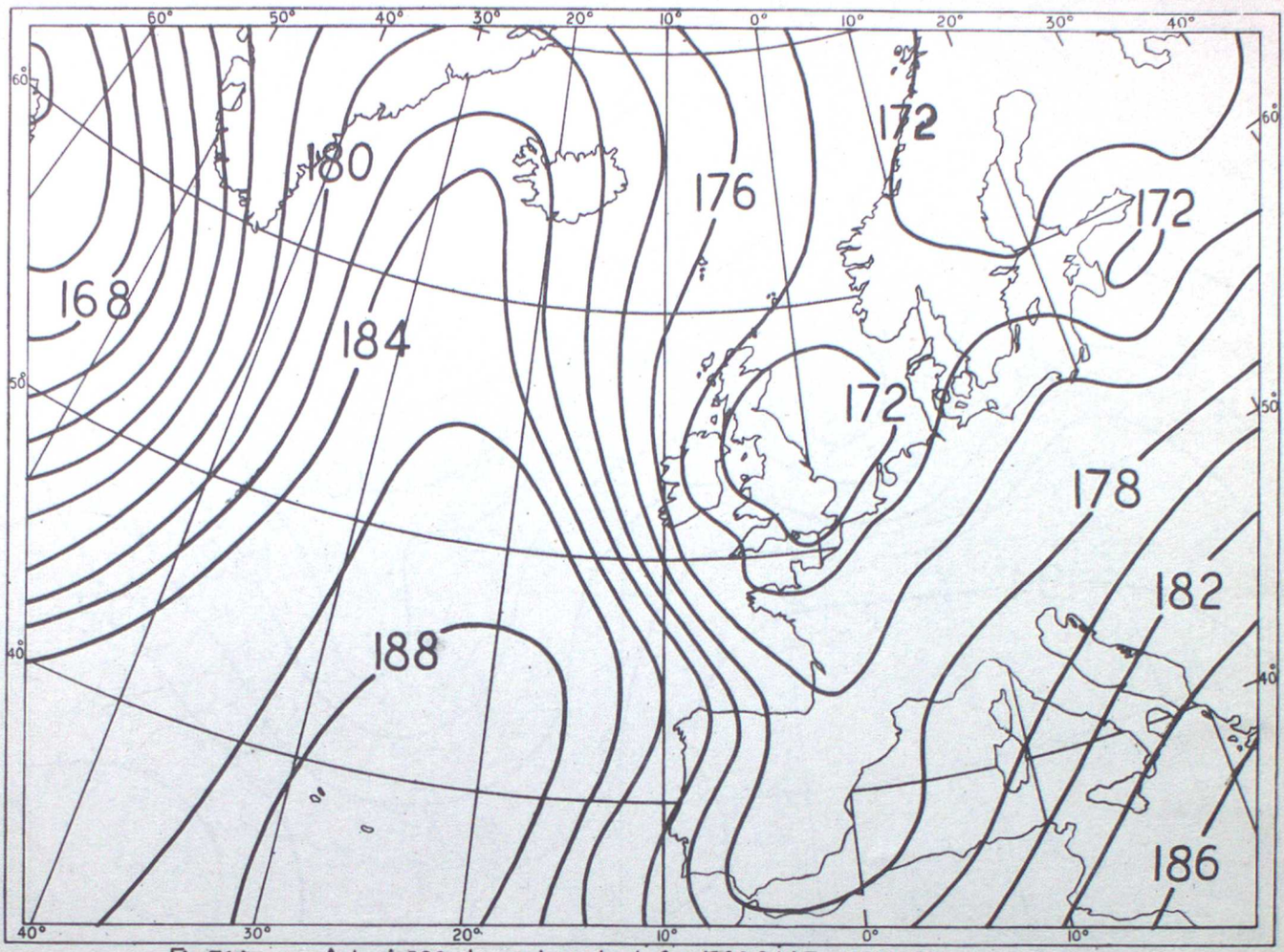

Fig.7(a) Actual 500mb. contour chart for 1500 G.M.T. 31.12.52

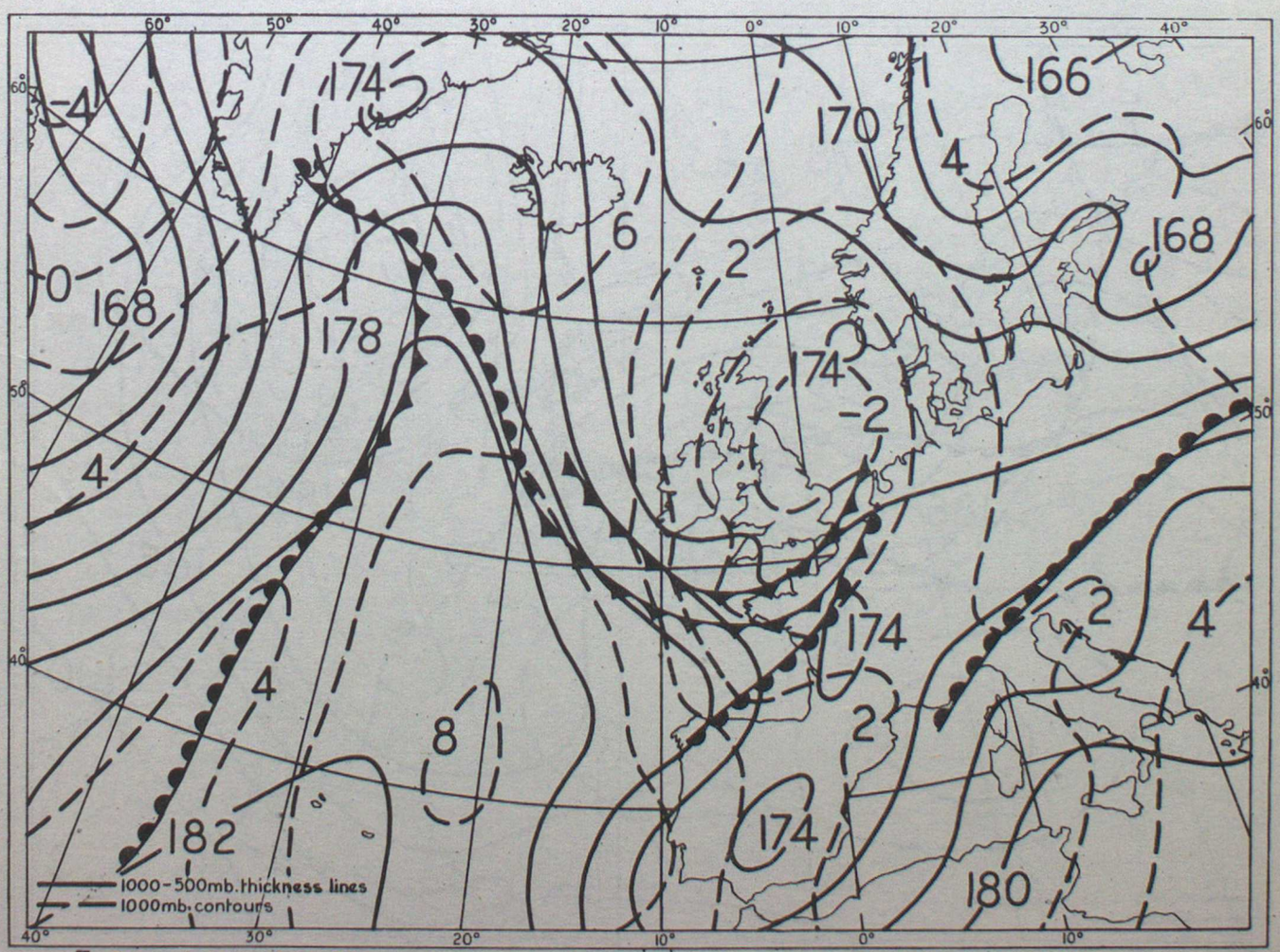

Fig.7(b) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 31.12.52

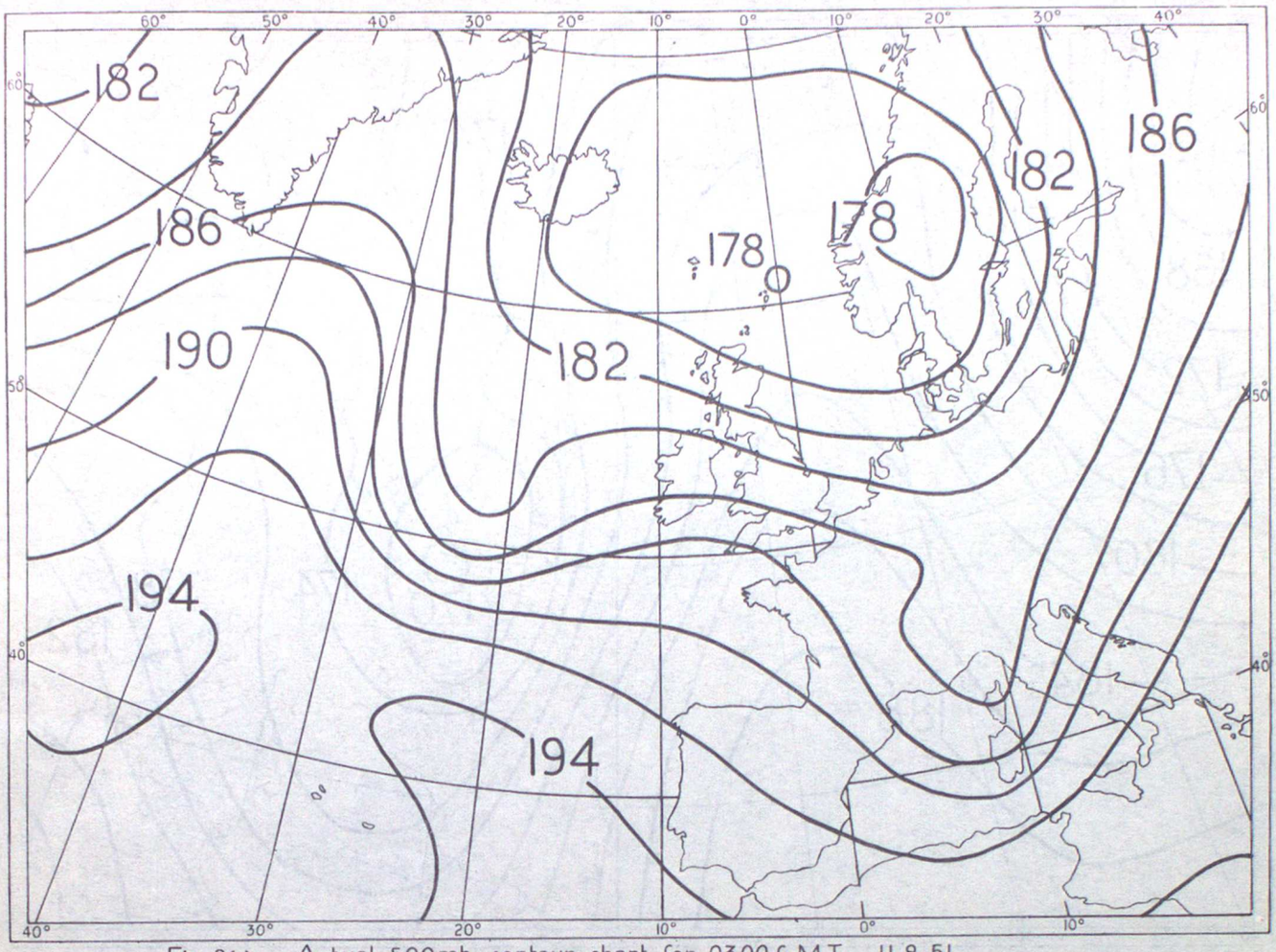

Fig. 2(c) Actual 500mb. contour chart for 0300 G.M.T. 11.8.51

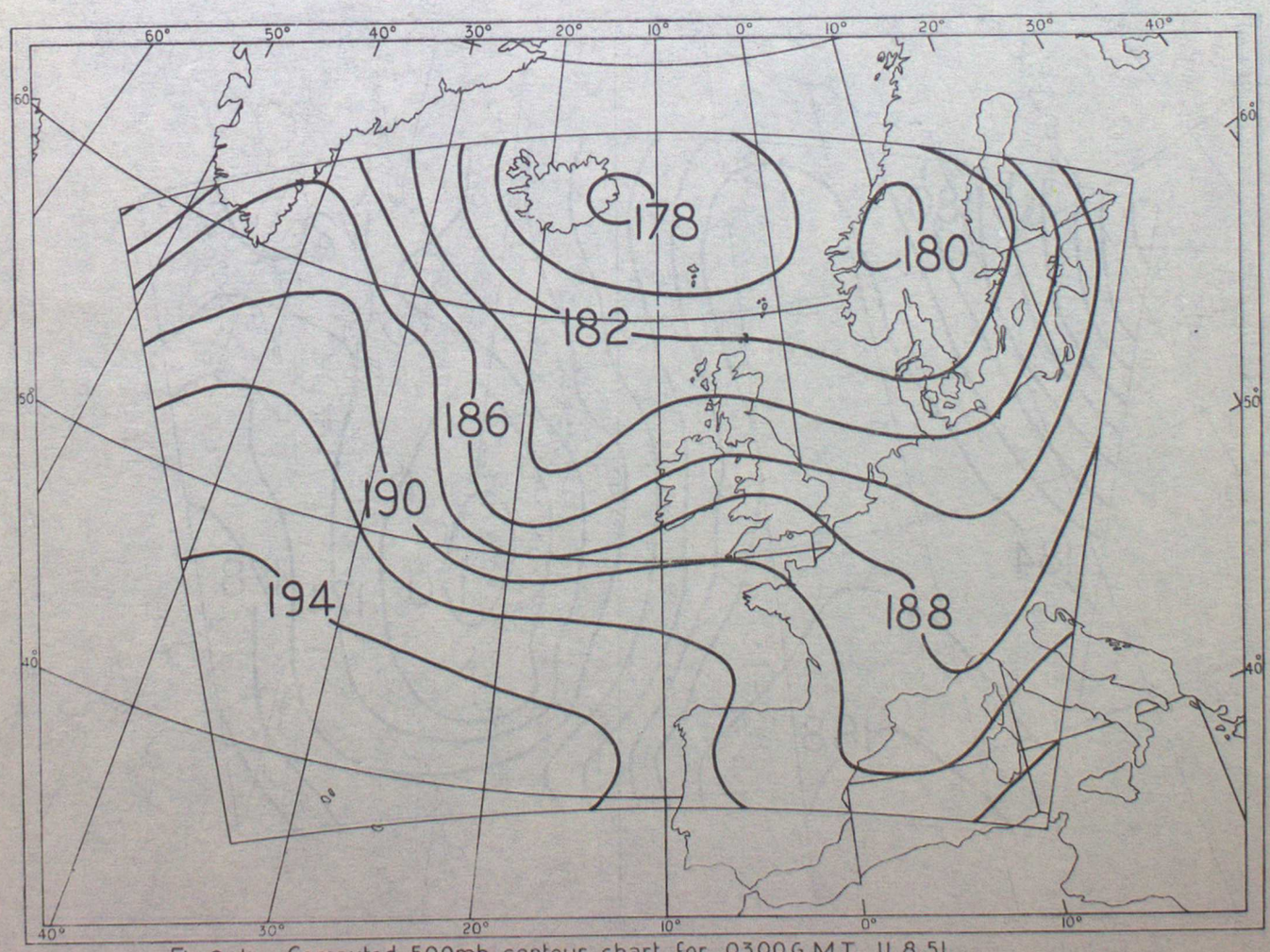

Fig. 2(d) Computed 500mb. contour chart for 0300 G.M.T. 11.8.51

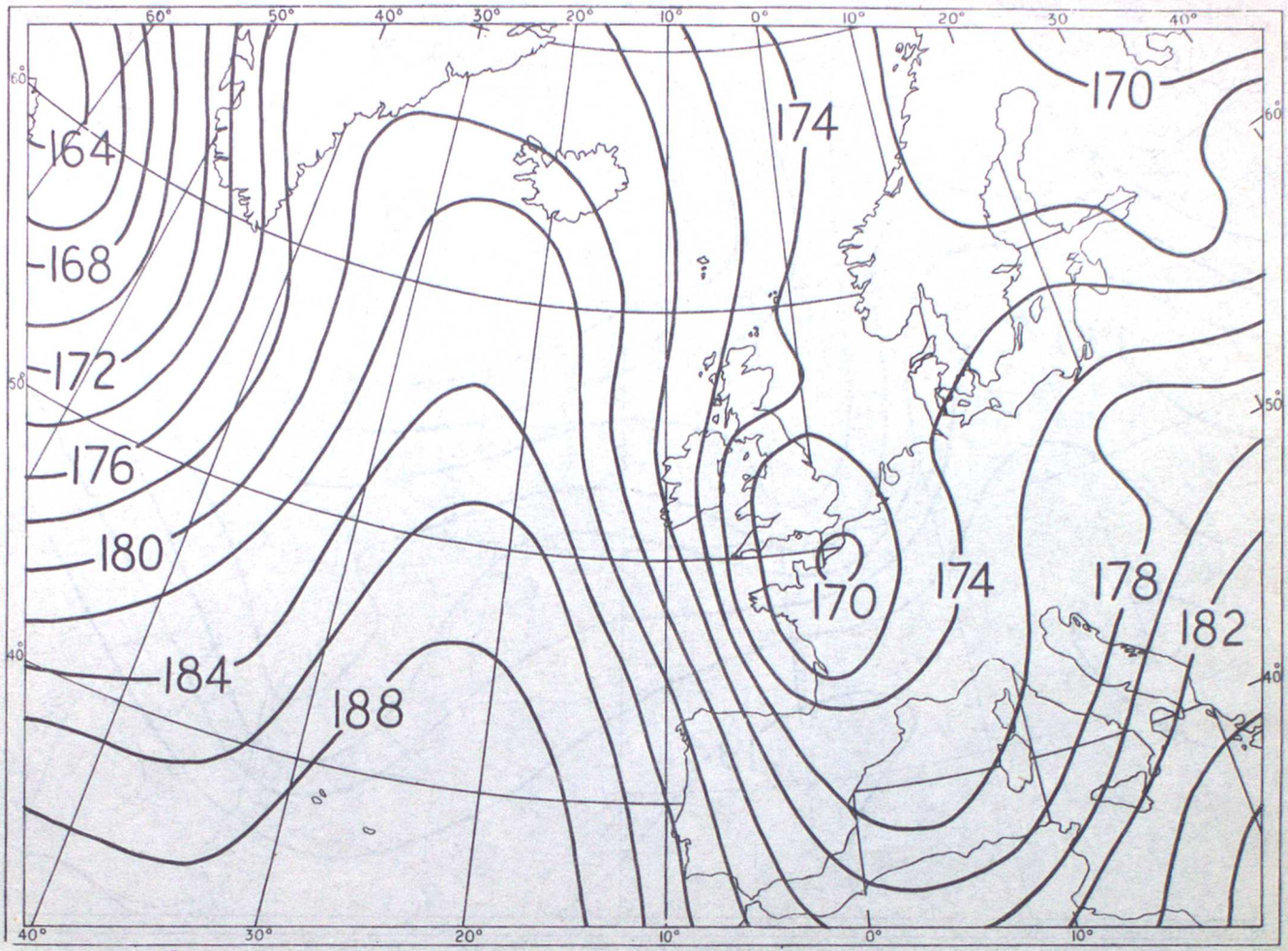

Fig.7(c) Actual 500mb. contour chart for 0300 G.M.T. 1.1.53

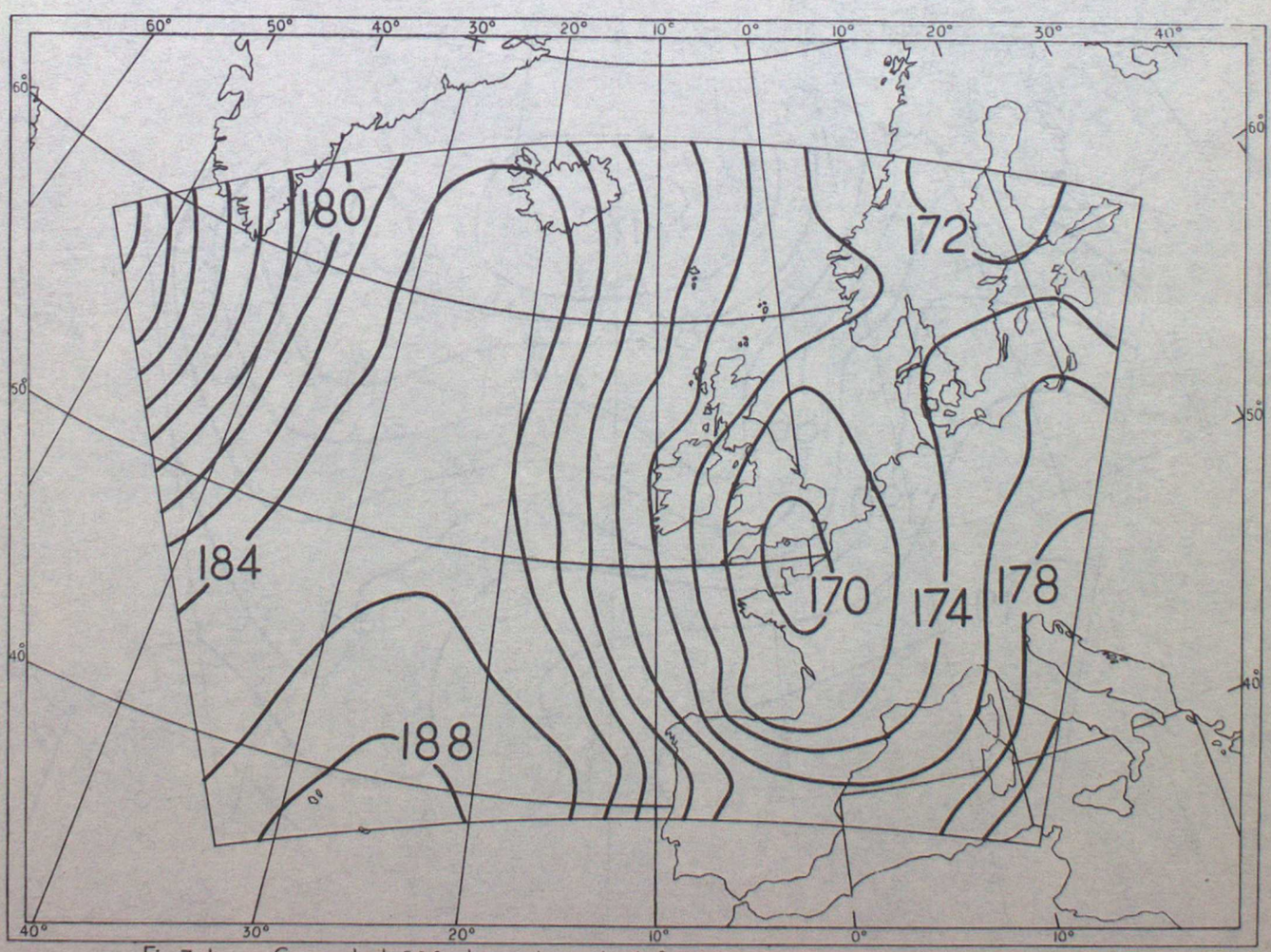

Fig.7(d) Computed 500mb. contour chart for 0300 G.M.T. 1.1.53

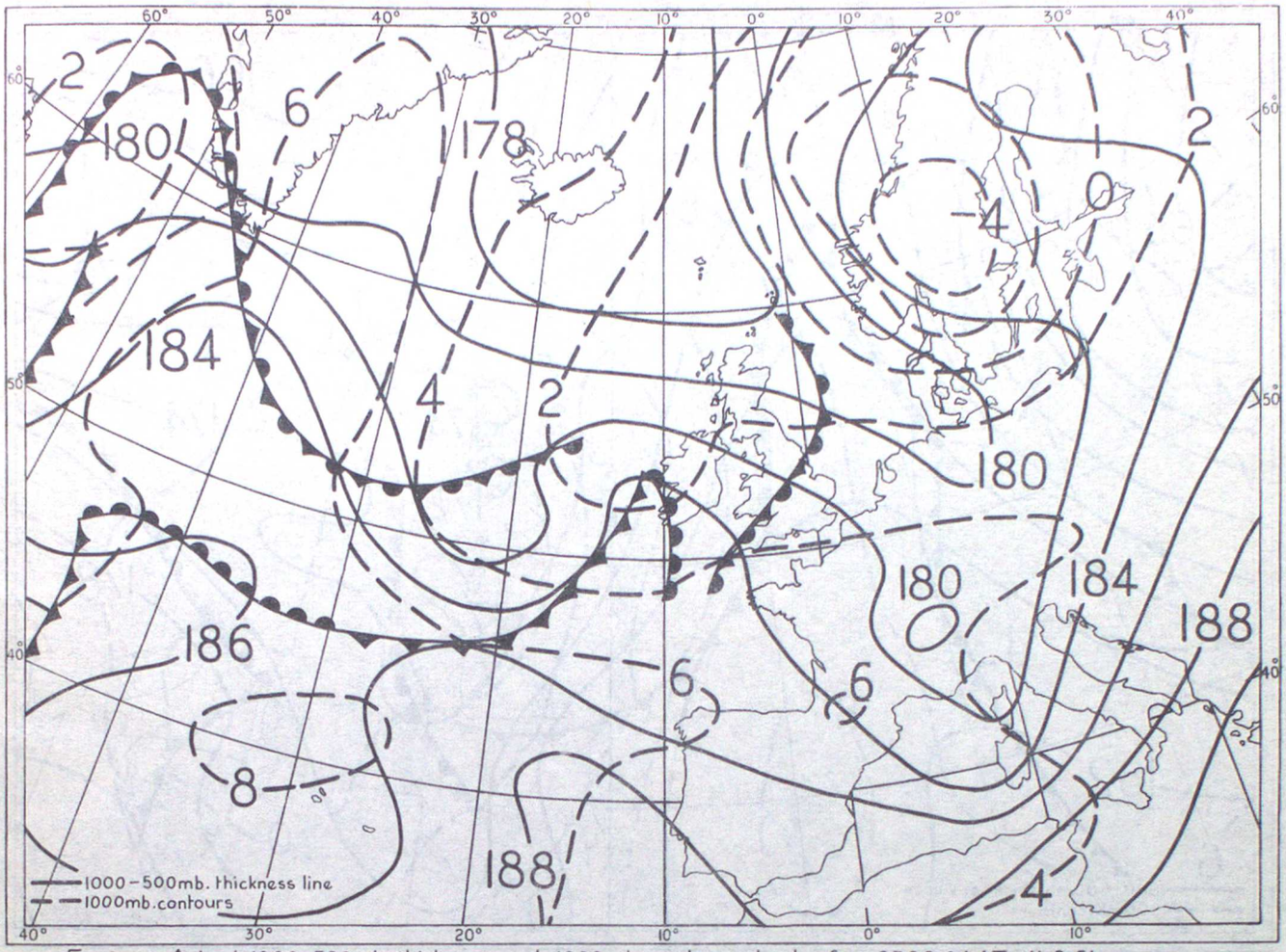

Fig.2(e) Actual 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 11.8.51

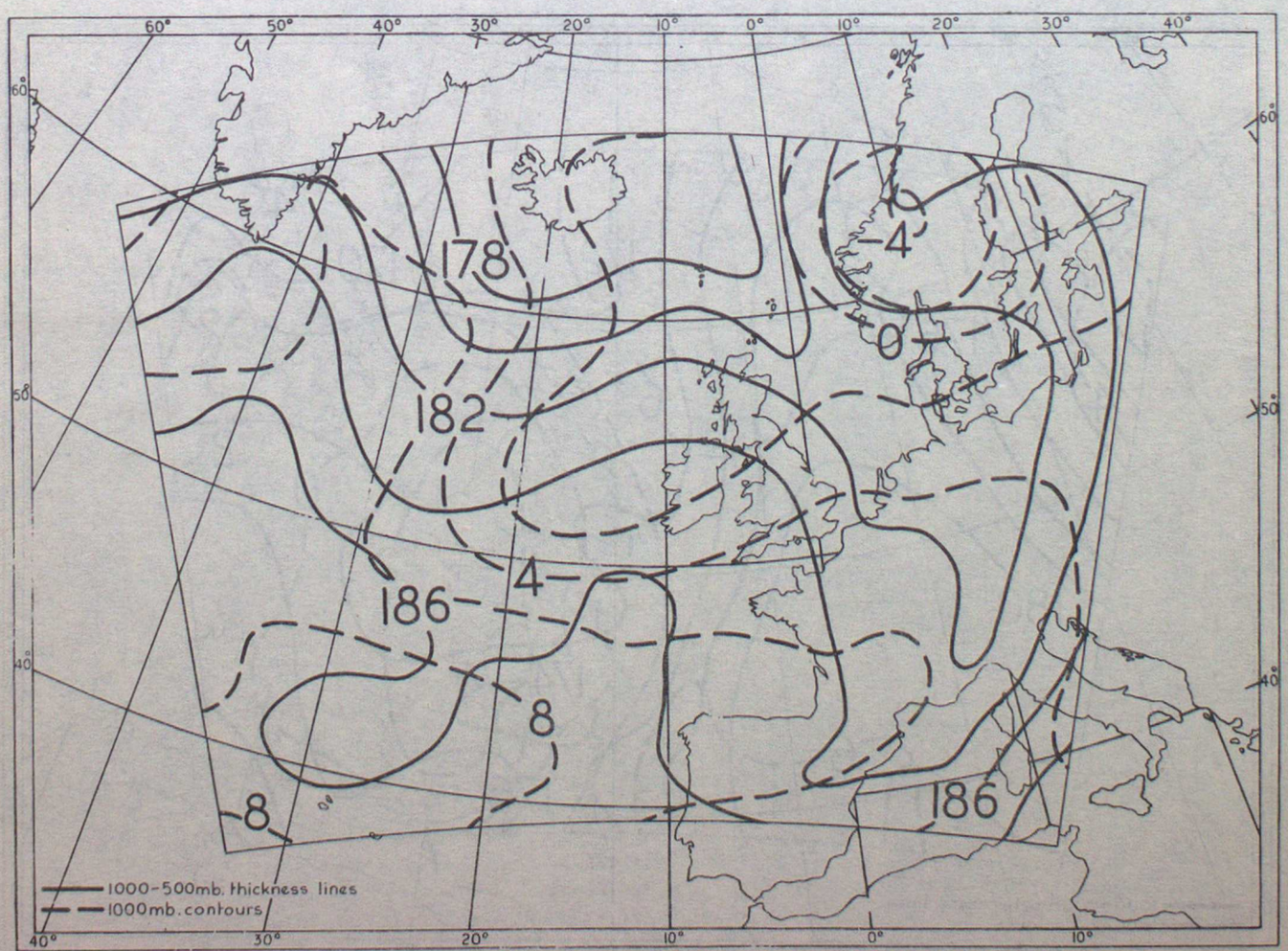

Fig.2(f) Computed 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 11.8.51

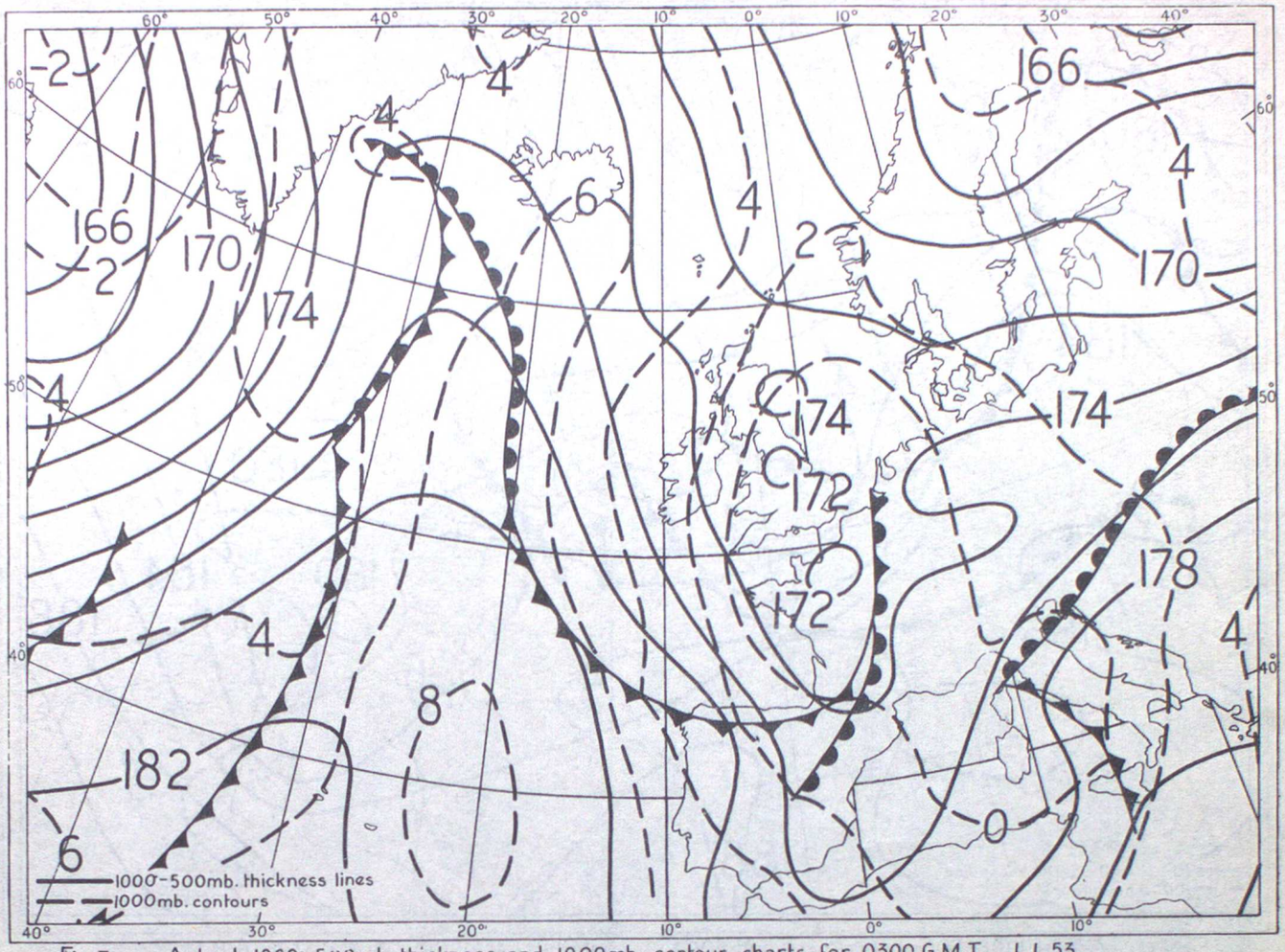

Fig.7(e) Actual. 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 1.1.53

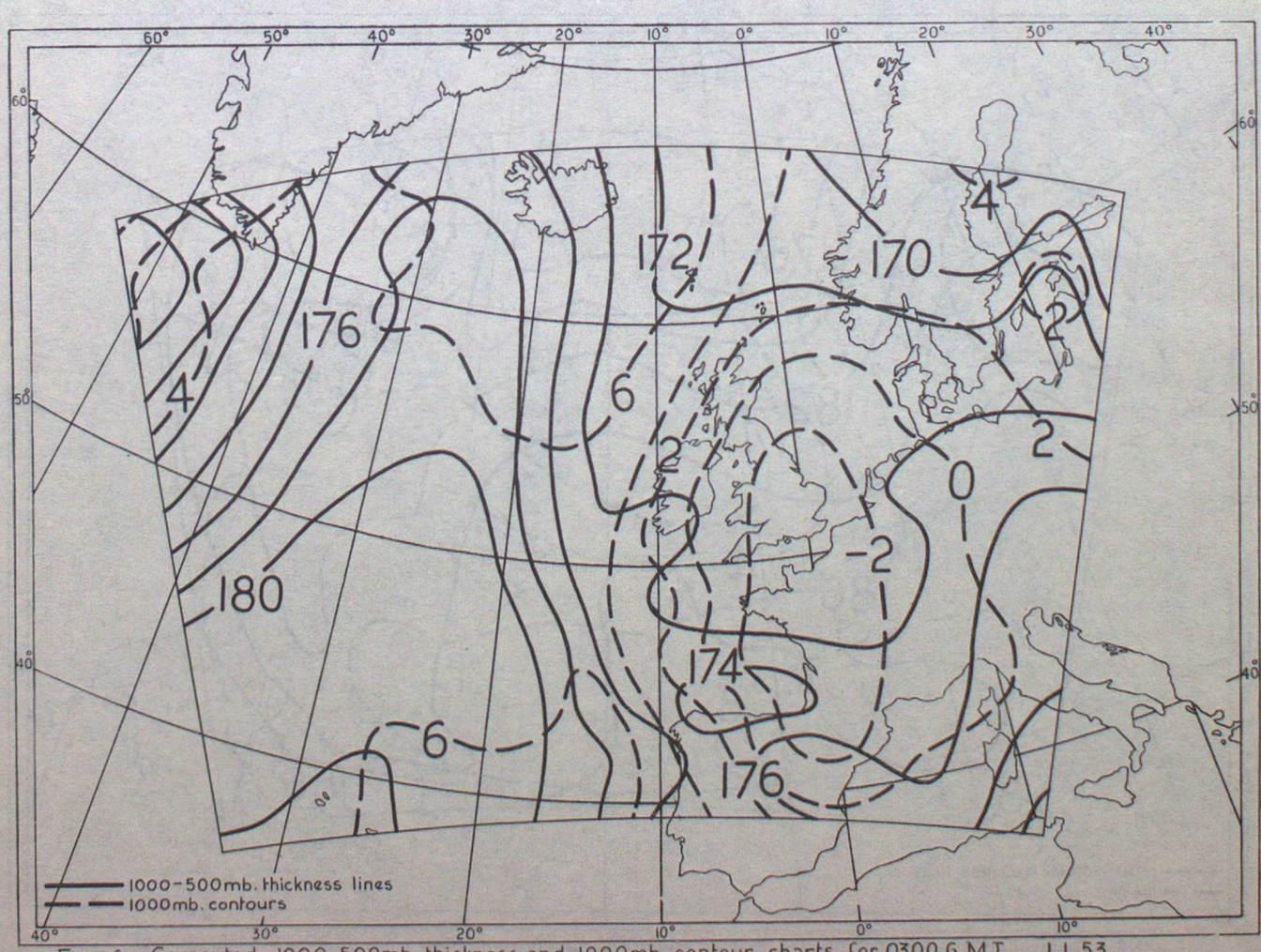

Fig.7(f) Computed 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 1.1.53

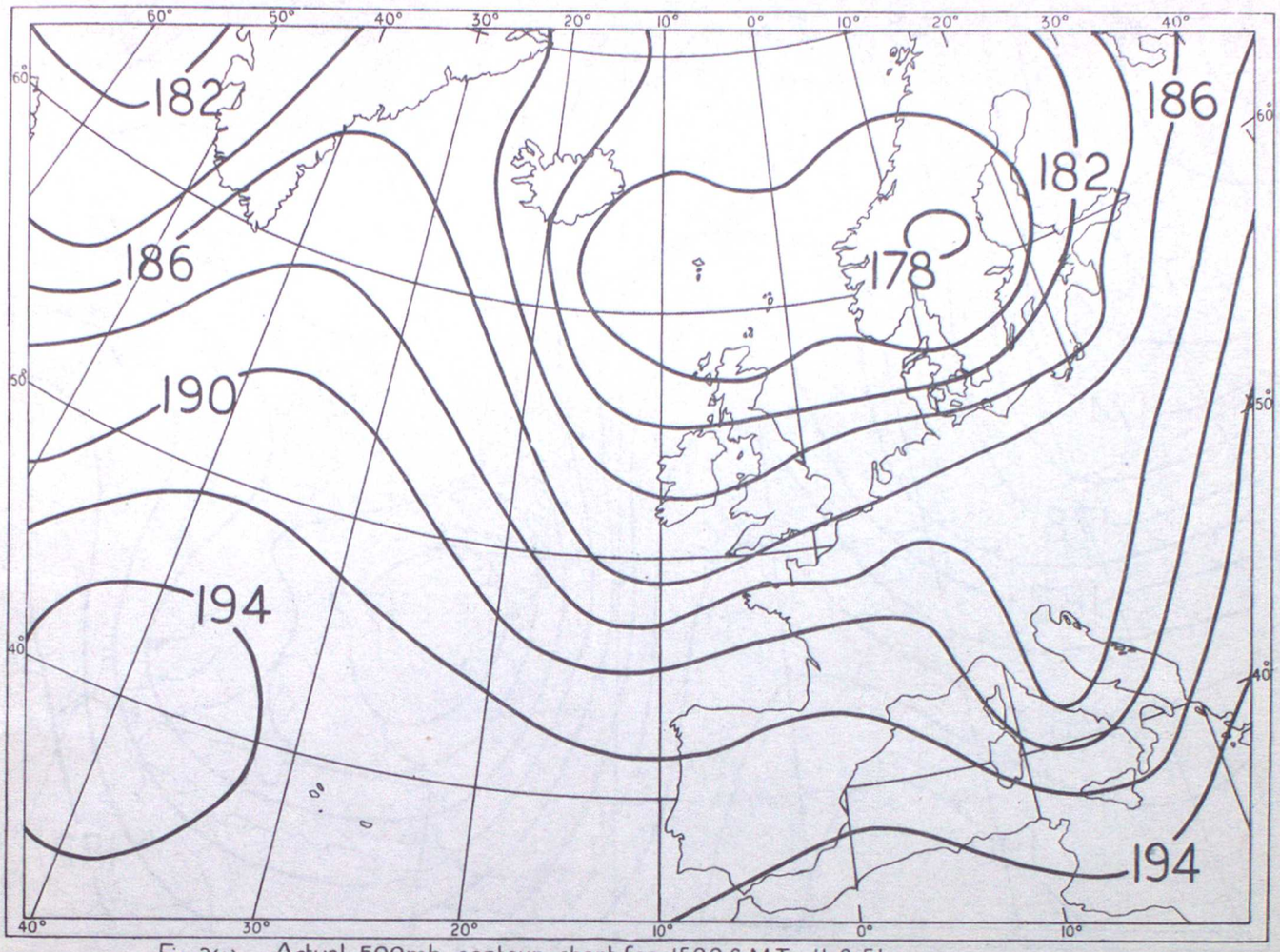

Fig.2(g) Actual 500mb. contour chart for 1500 G.M.T. 11.8.51

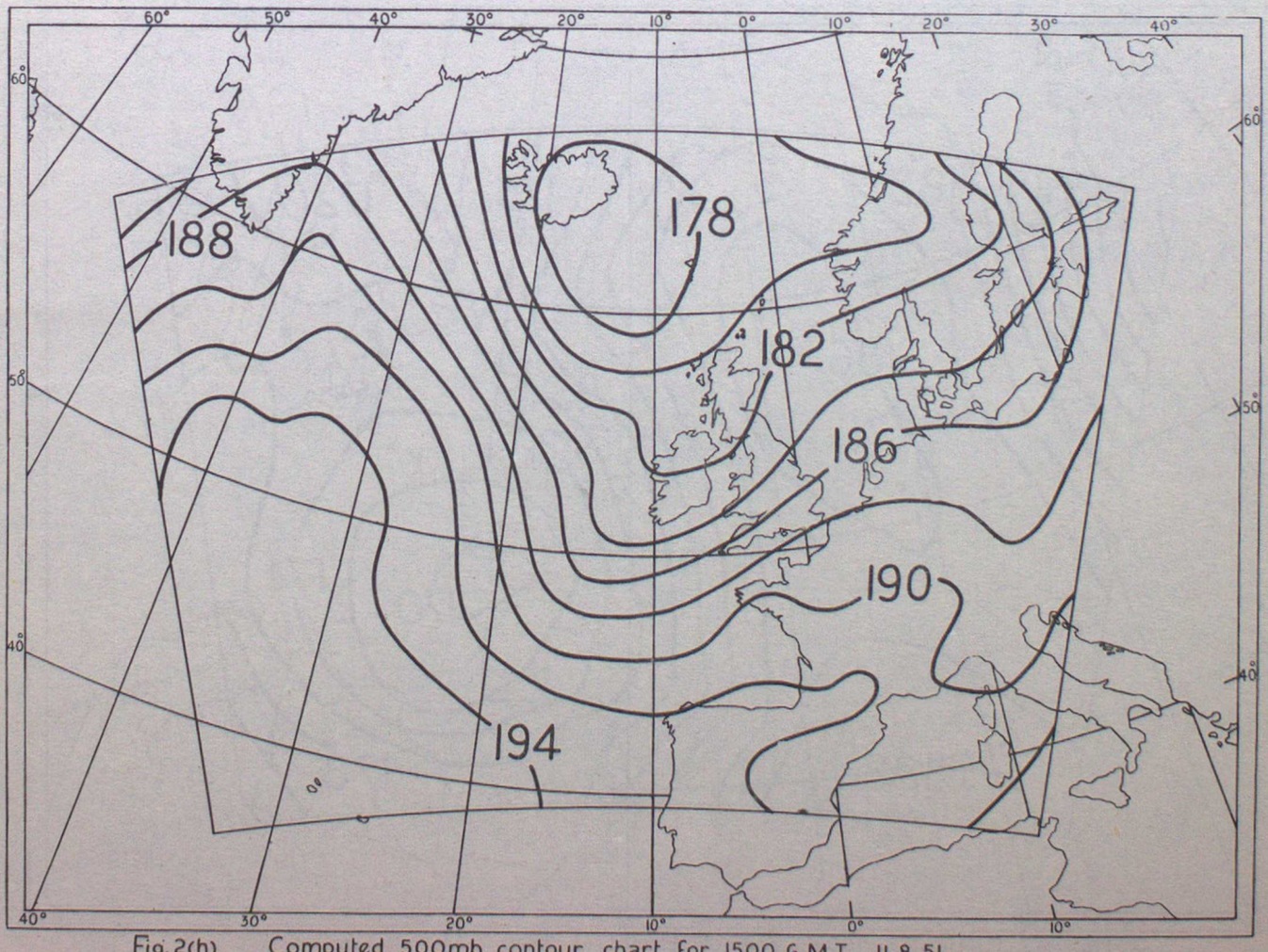

Fig.2(h) Computed 500mb. contour chart for 1500 G.M.T. 11.8.51

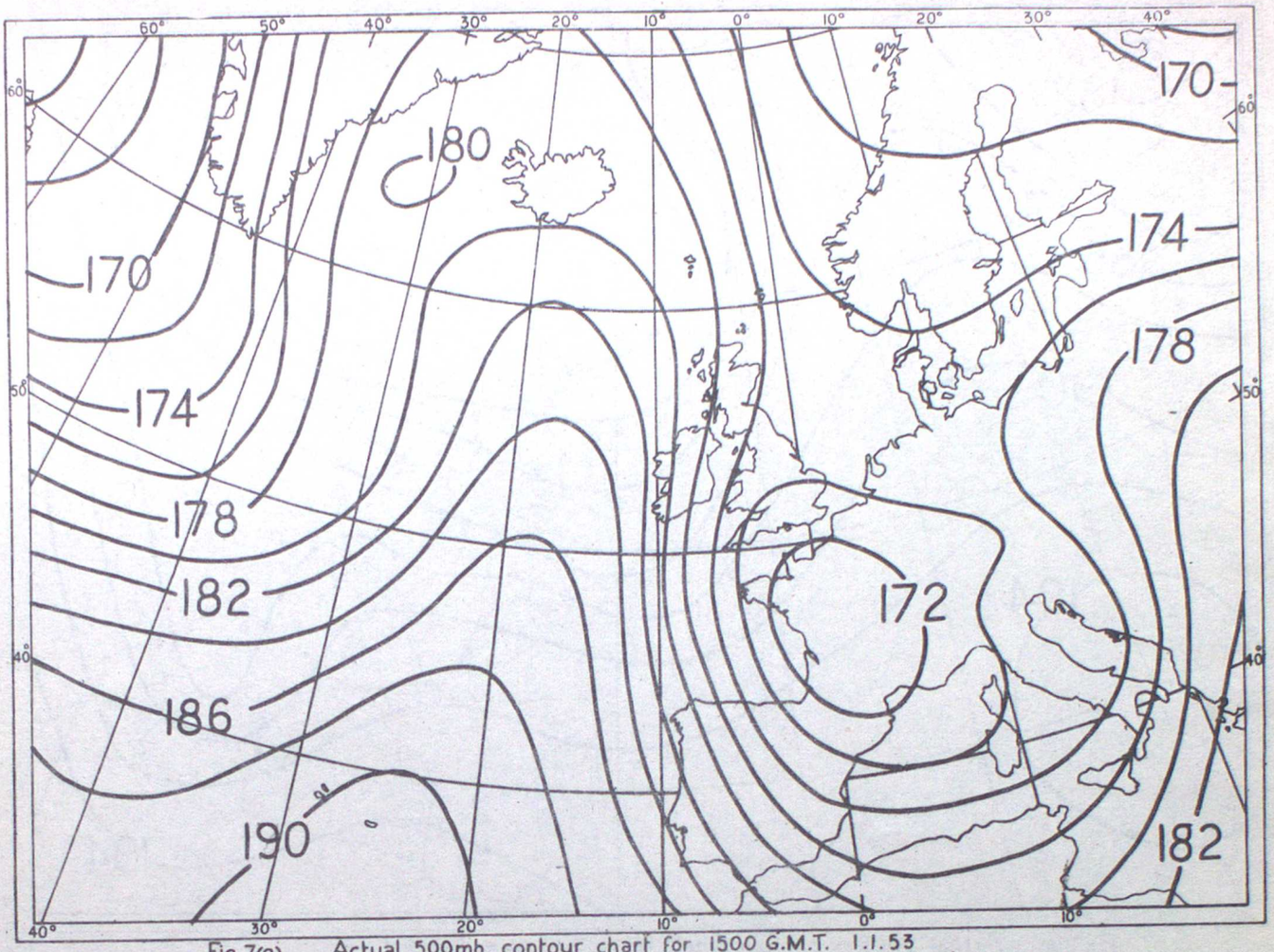

Fig.7(g) Actual 500mb. contour chart for 1500 G.M.T. 1.1.53

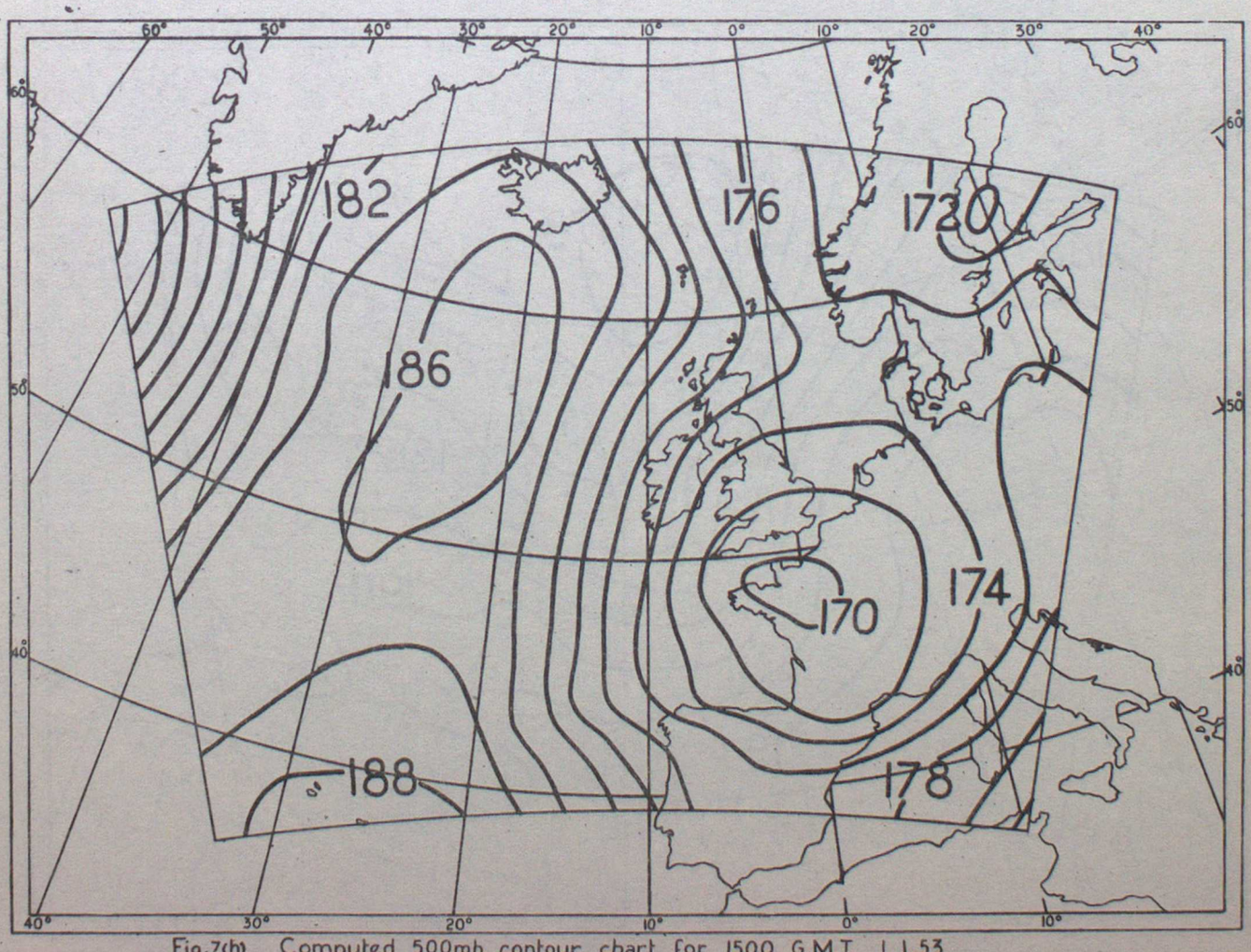

Fig.7(h) Computed 500mb. contour chart for 1500 G.M.T. 1.1.53

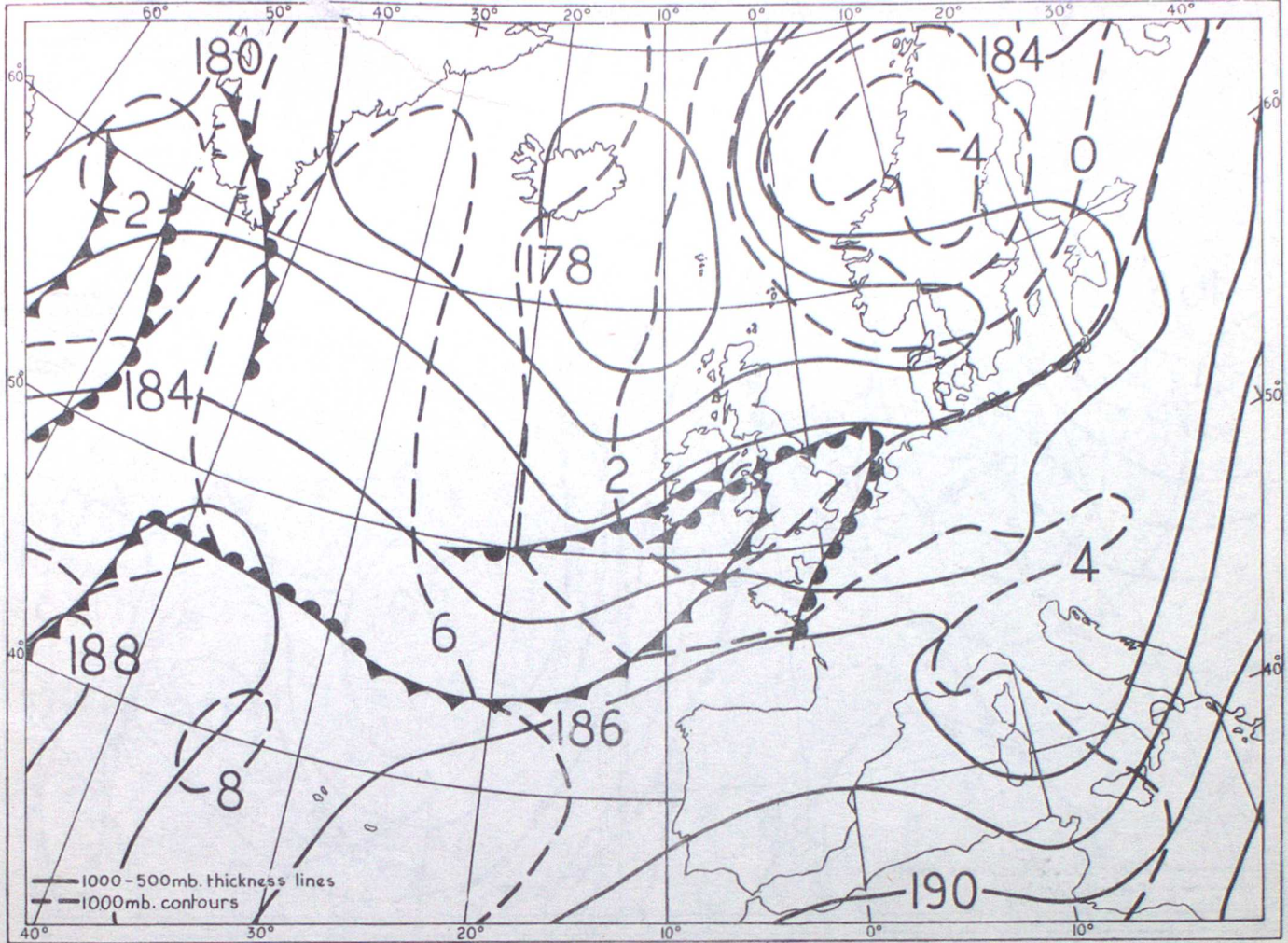

Fig.2(i) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 11.8.51

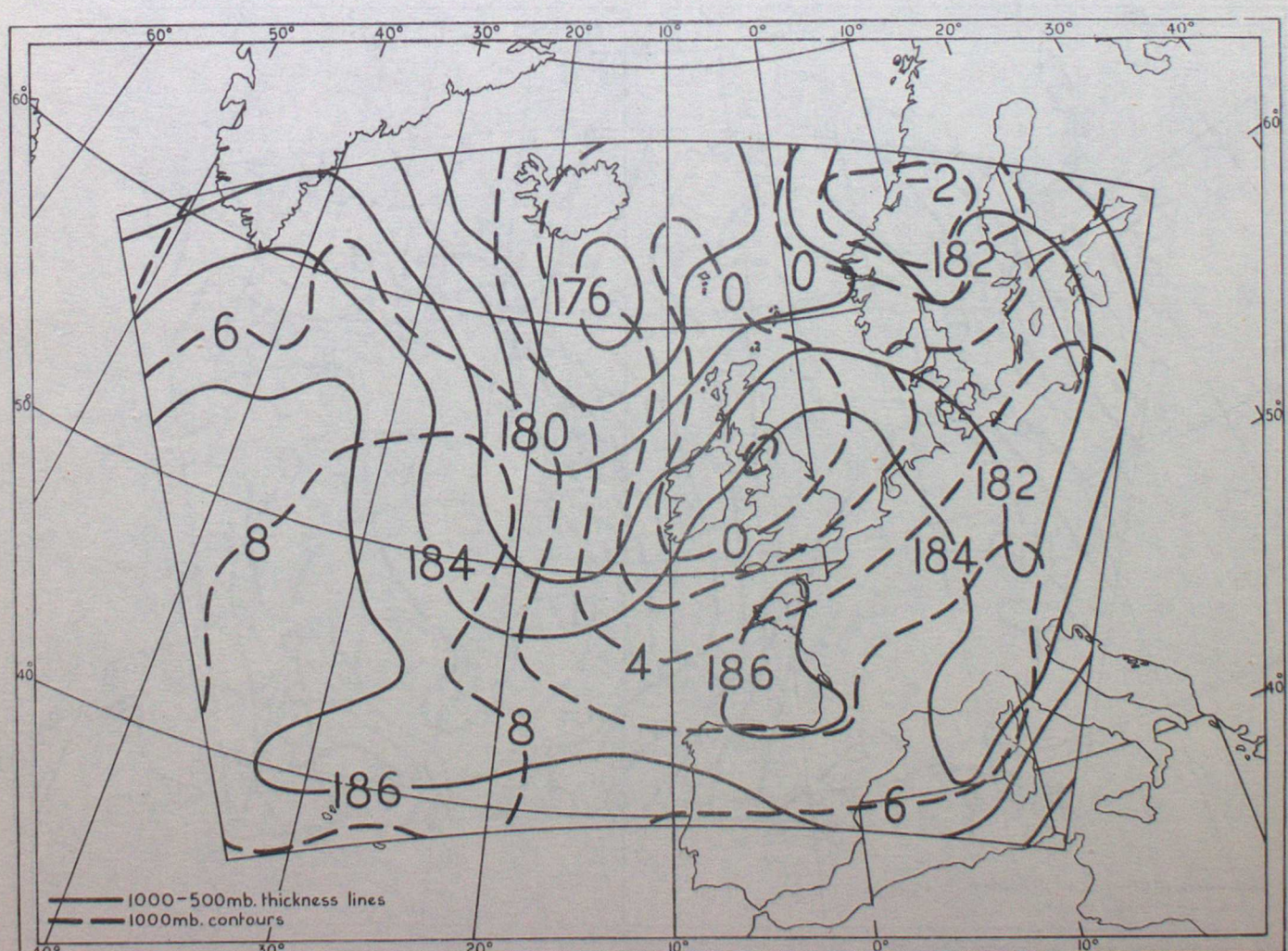

Fig.2(j) Computed 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 11.8.51

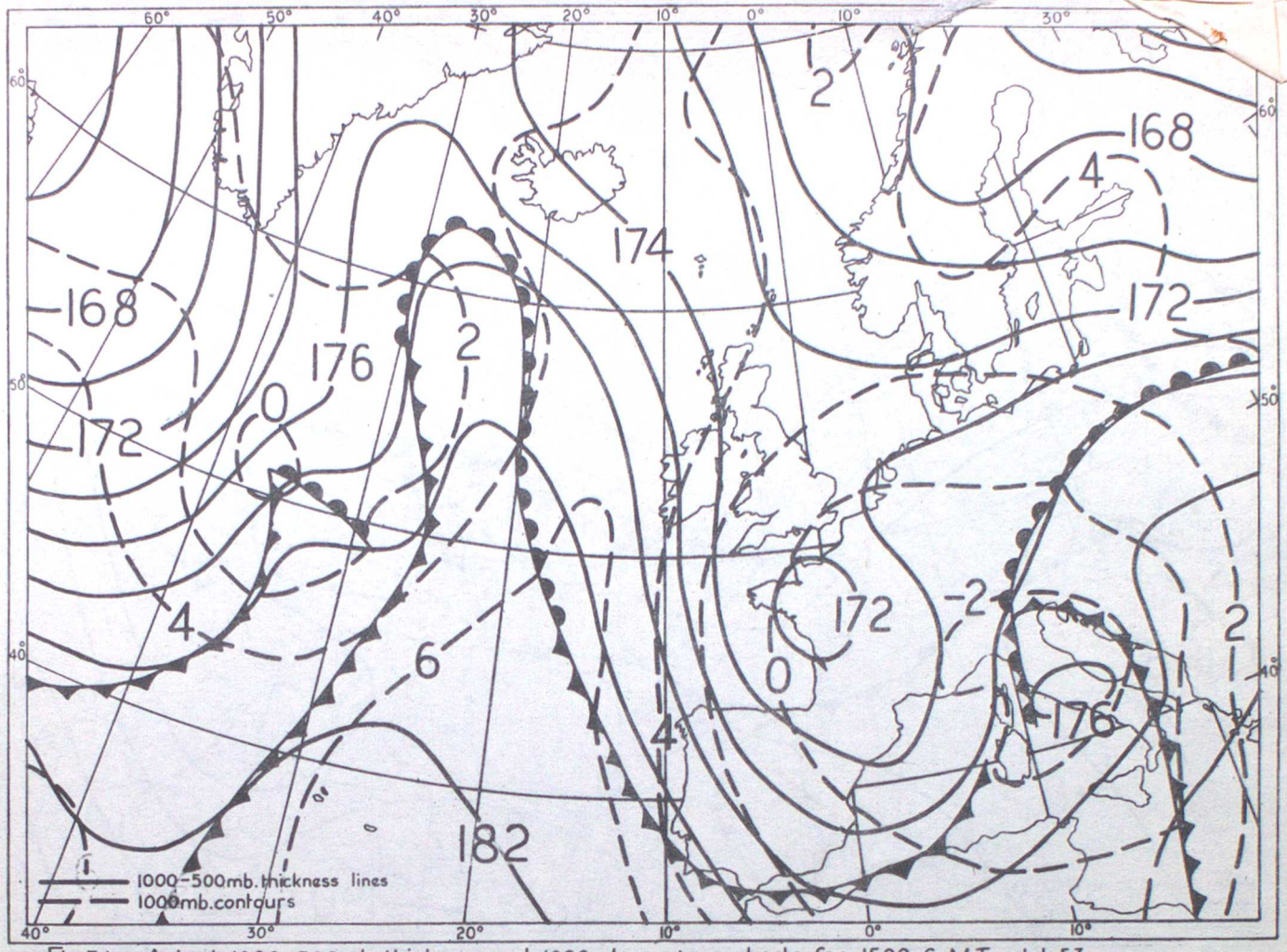

Fig.7(i) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 1.1.53

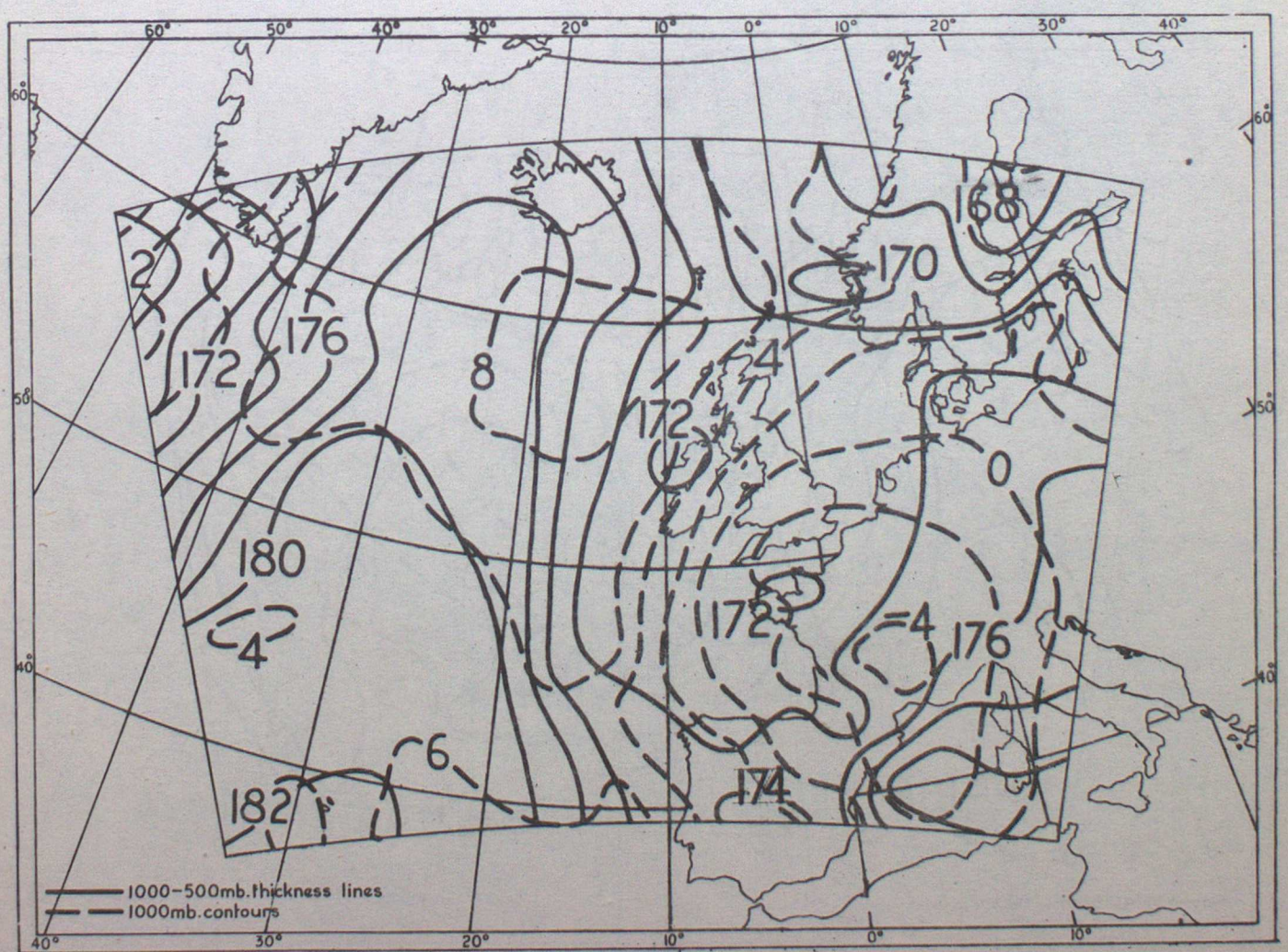

Fig.7(j) Computed 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 1.1.53

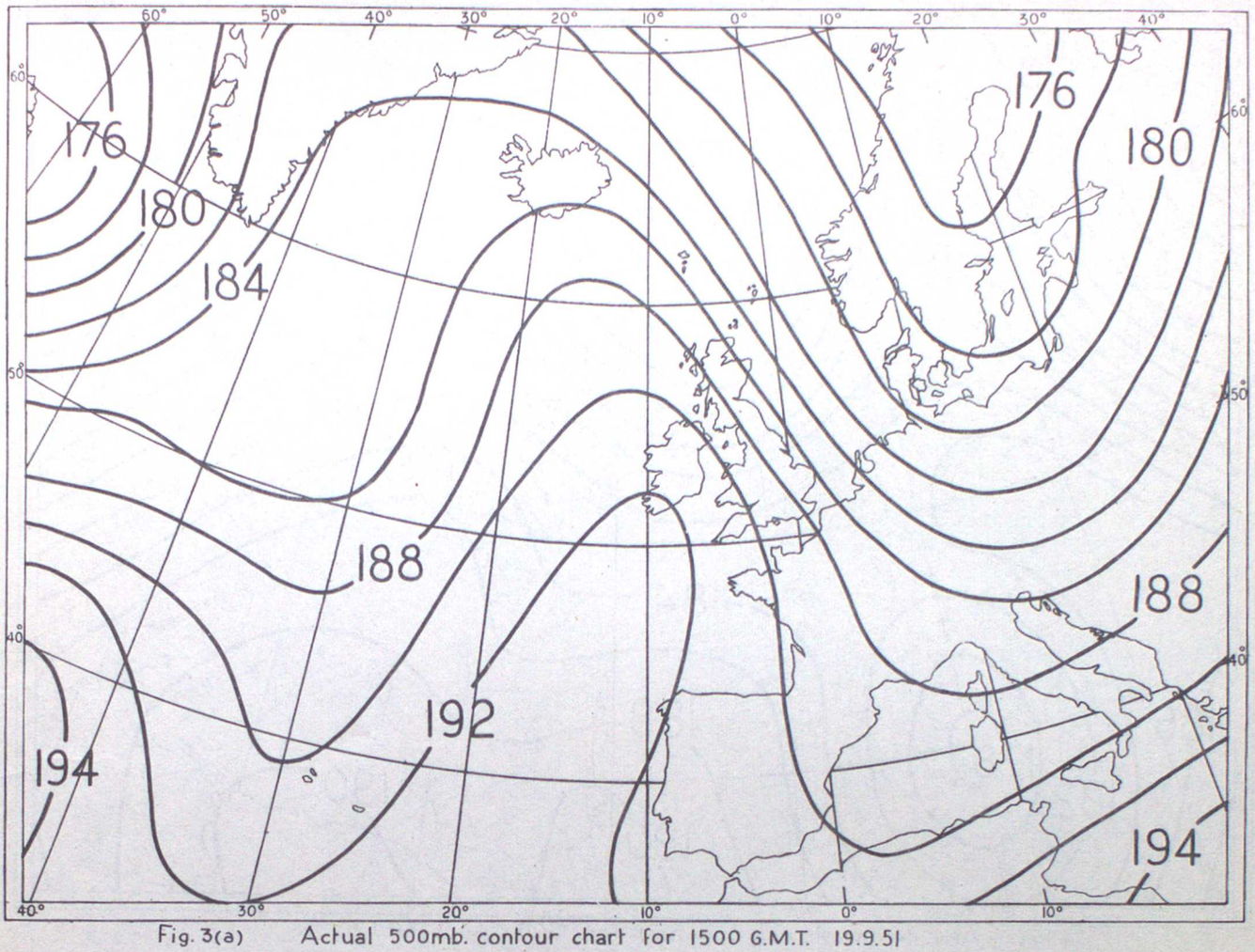

Fig. 3(a) Actual 500mb. contour chart for 1500 G.M.T. 19.9.51

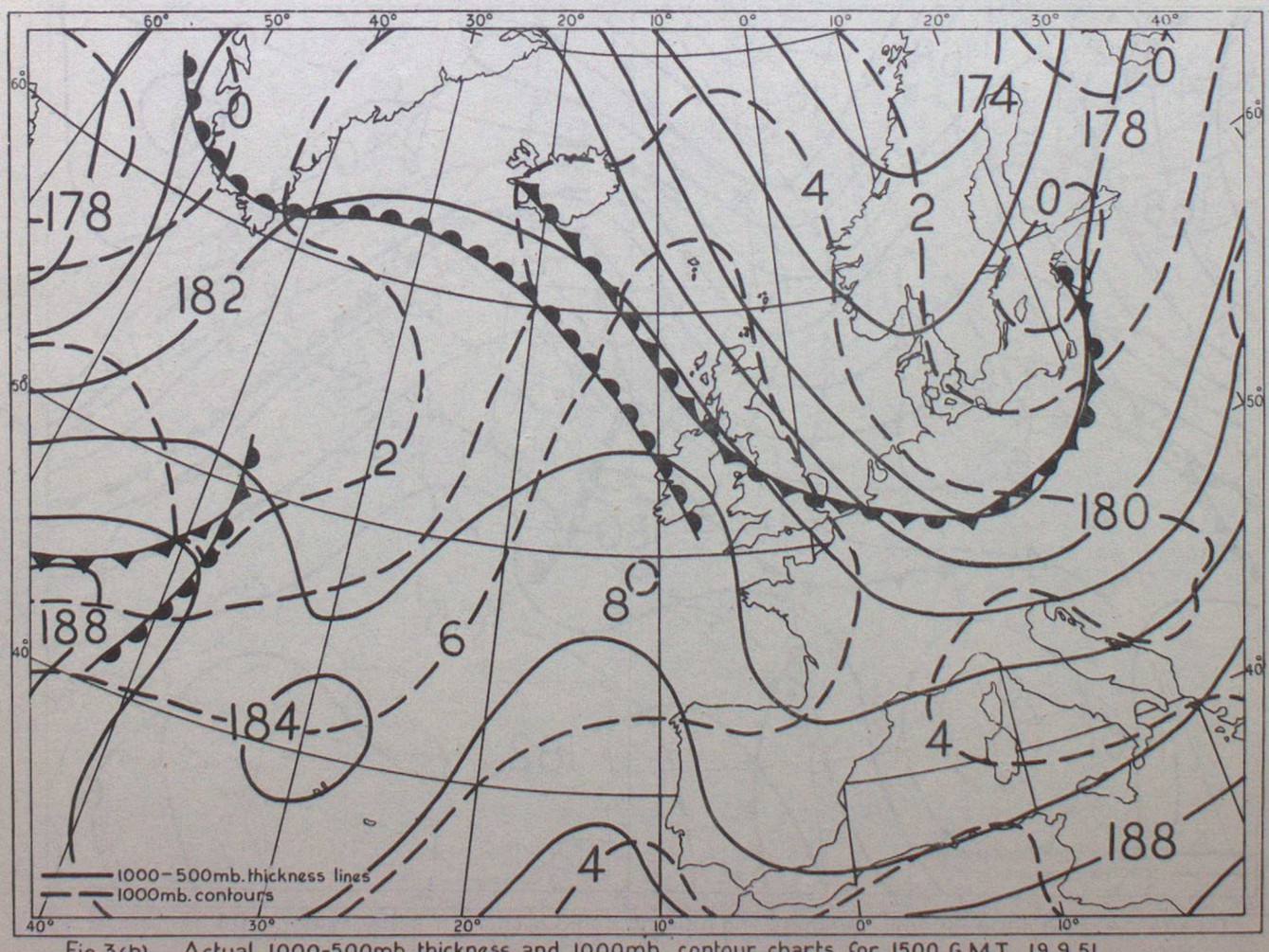

Fig. 3(b) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 19.9.51

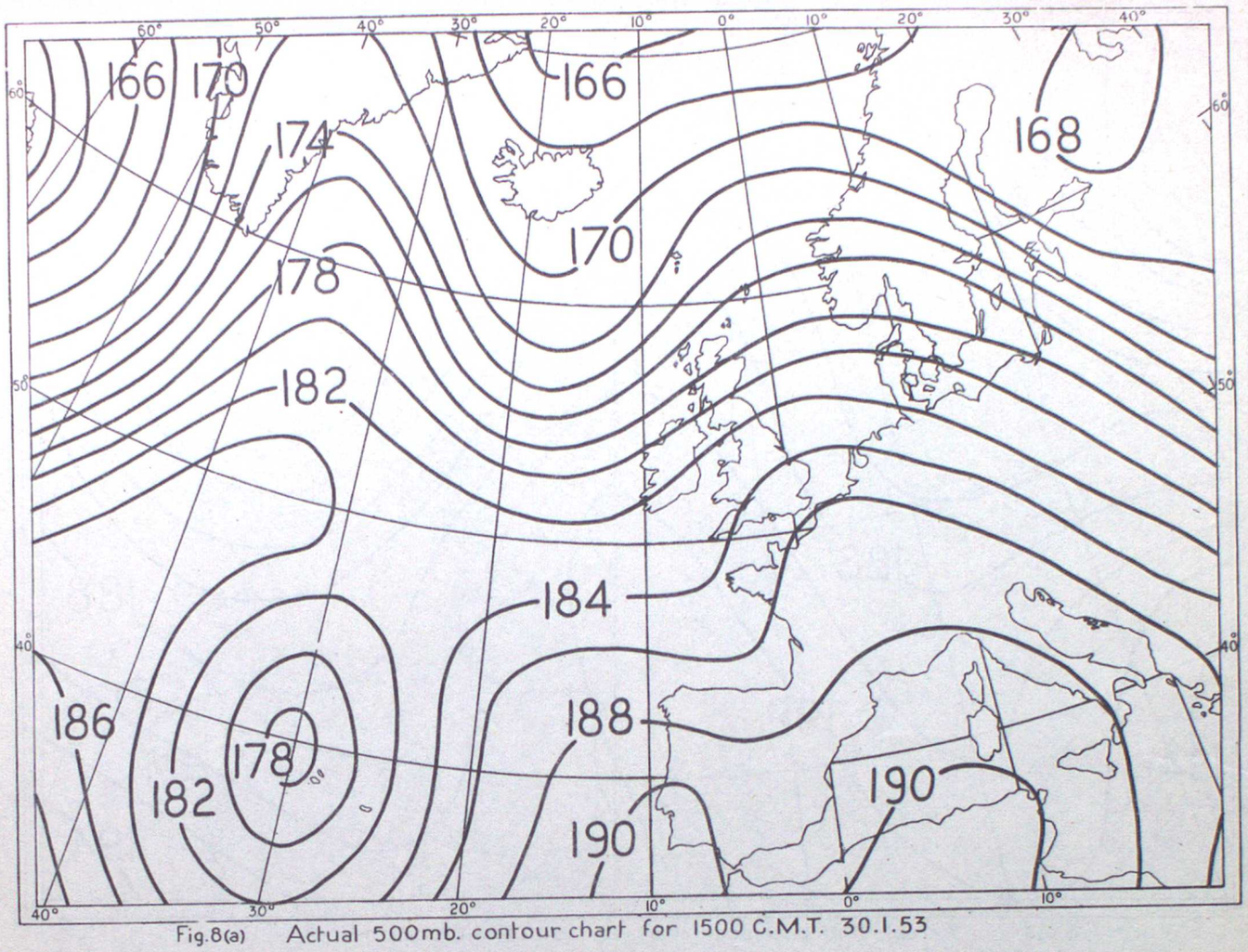

Fig.8(a) Actual 500mb. contour chart for 1500 G.M.T. 30.1.53

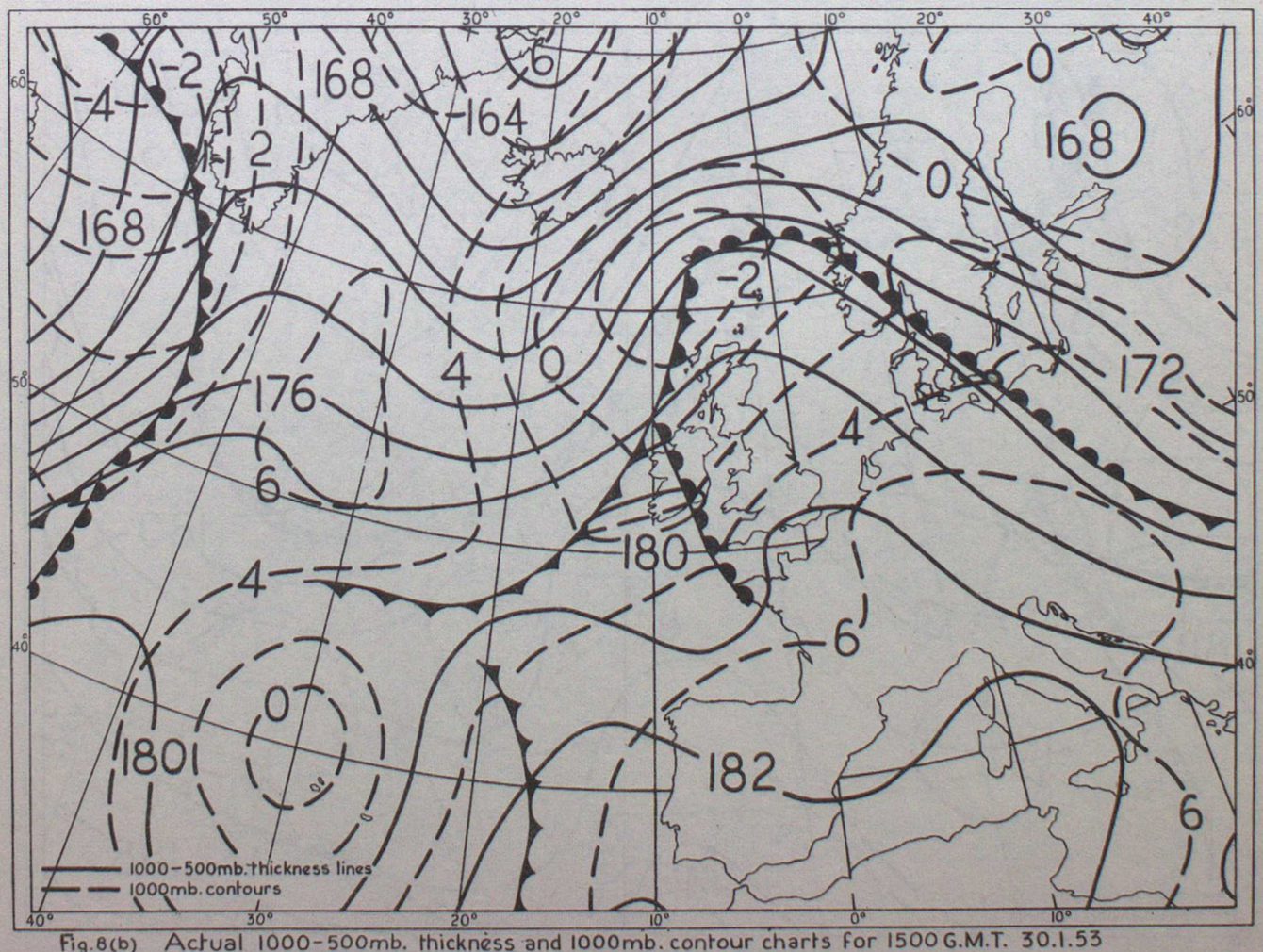

Fig.8(b) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 30.1.53

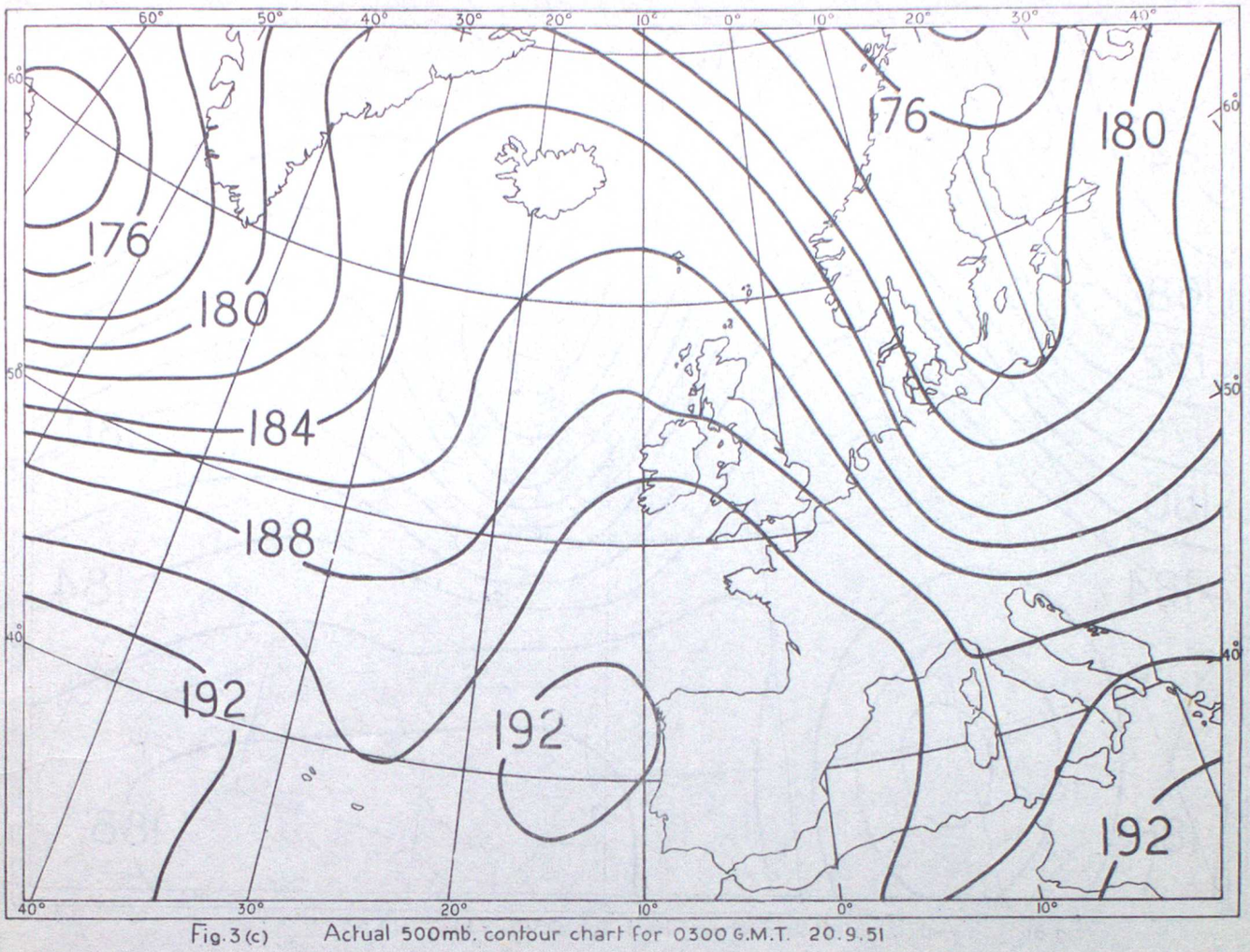

Fig.3(c) Actual 500mb. contour chart for 0300 G.M.T. 20.9.51

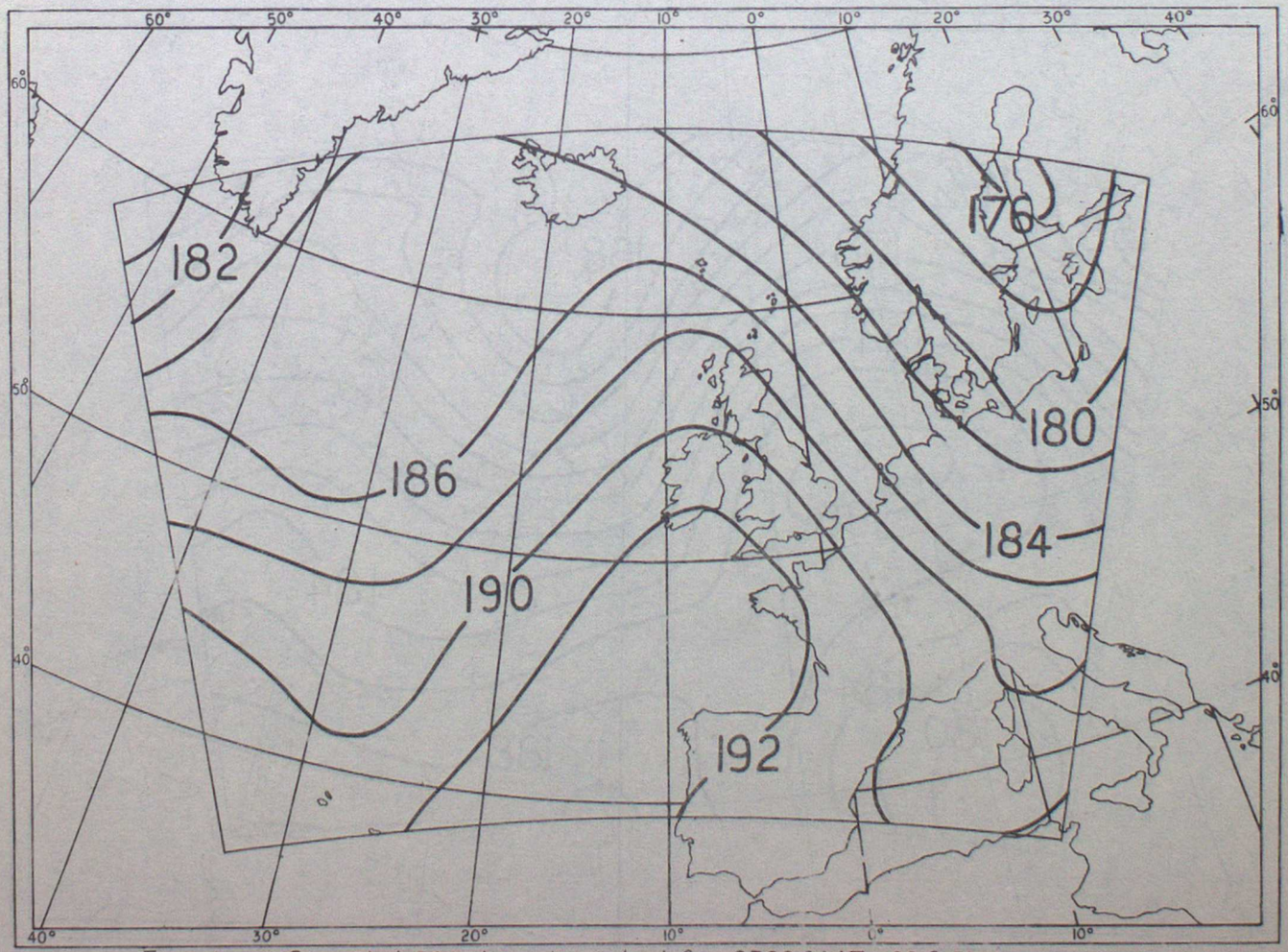

Fig.3(d) Computed 500mb. contour chart for 0300 G.M.T. 20.9.51

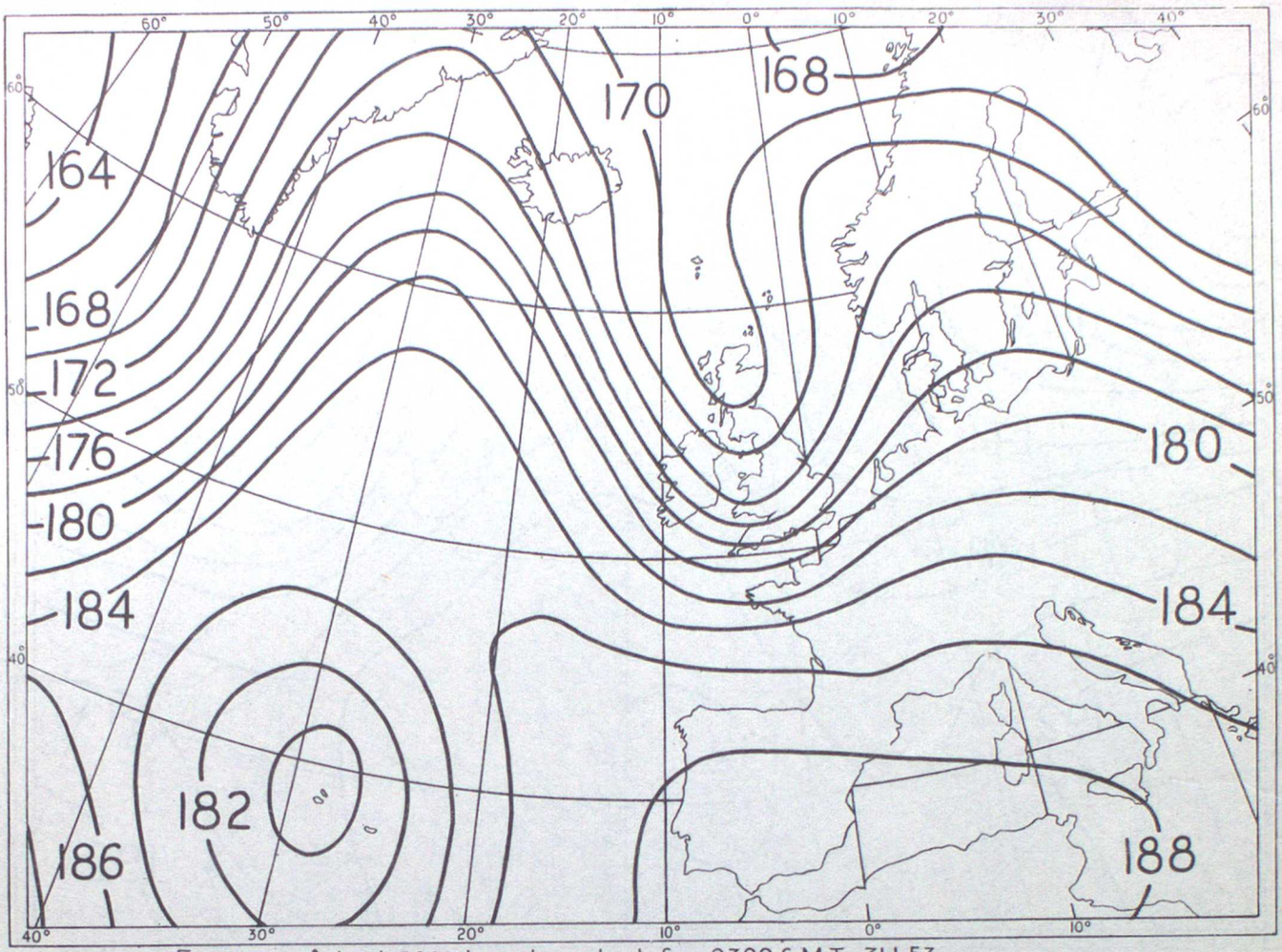

Fig. 8(c) Actual 500mb. contour chart for 0300 G.M.T. 31.1.53

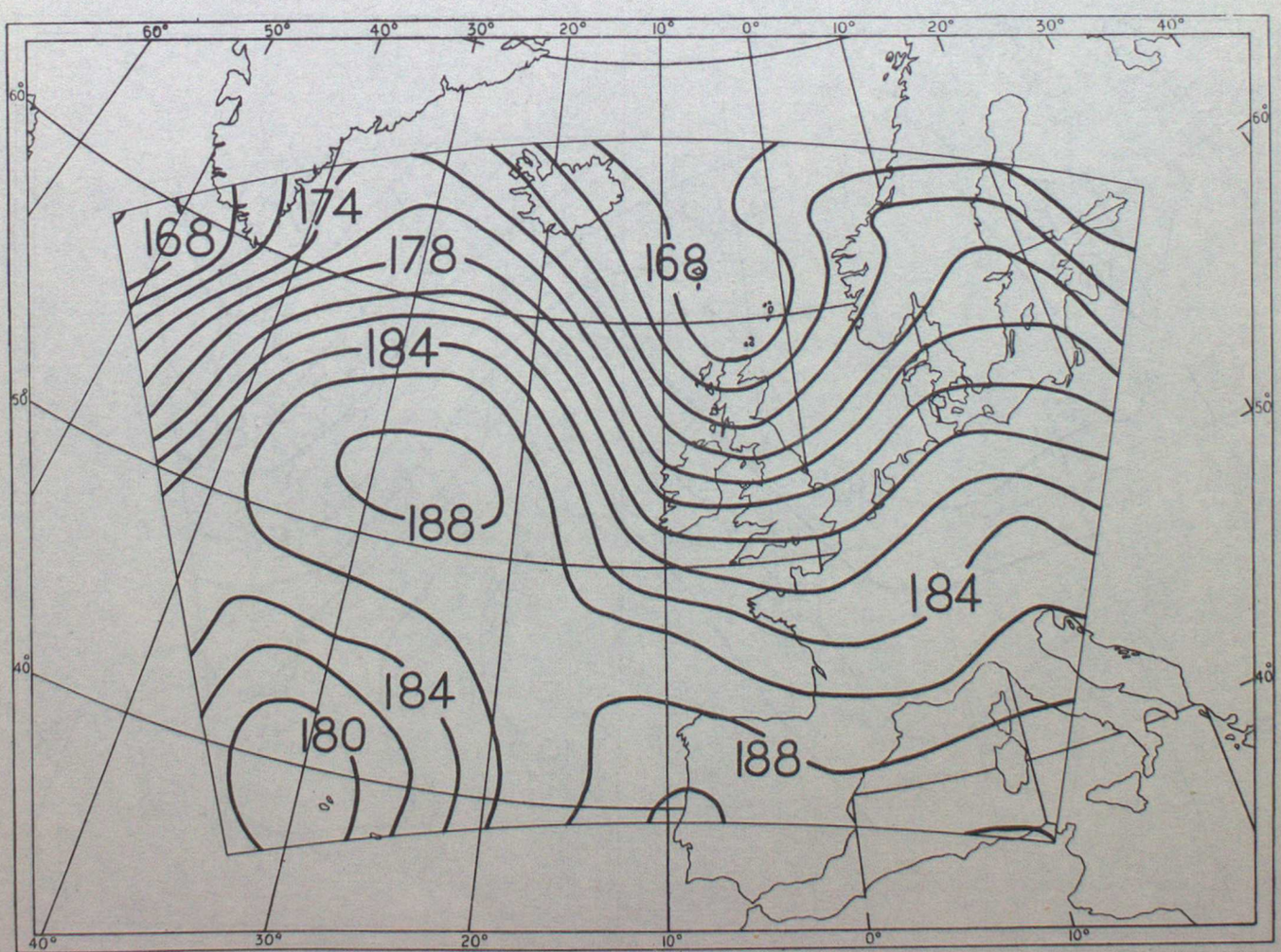

Fig. 8(d) Computed 500mb. contour chart for 0300 G.M.T. 31.1.53

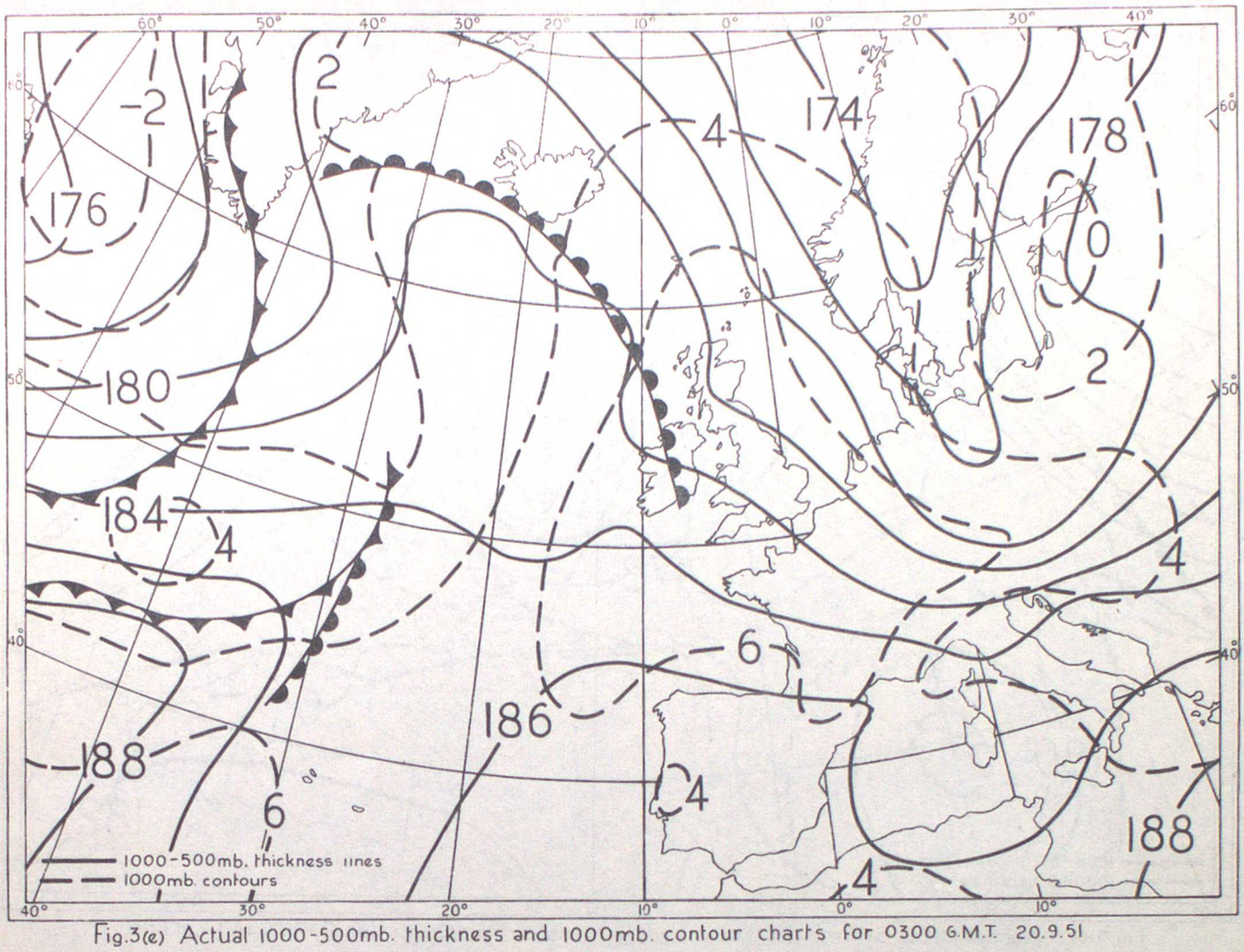

Fig.3(e) Actual 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 20.9.51

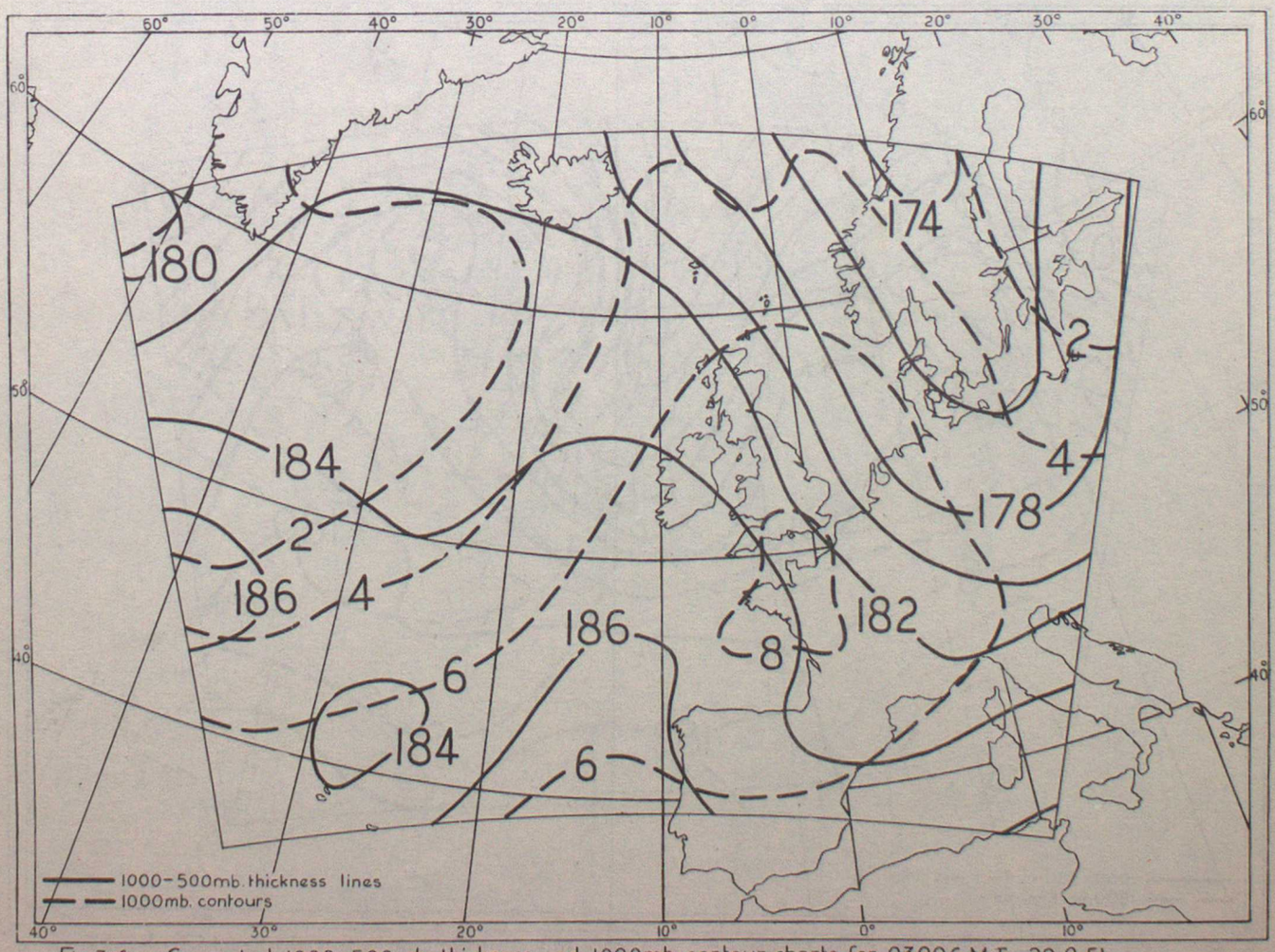

Fig.3(f) Computed 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 20.9.51

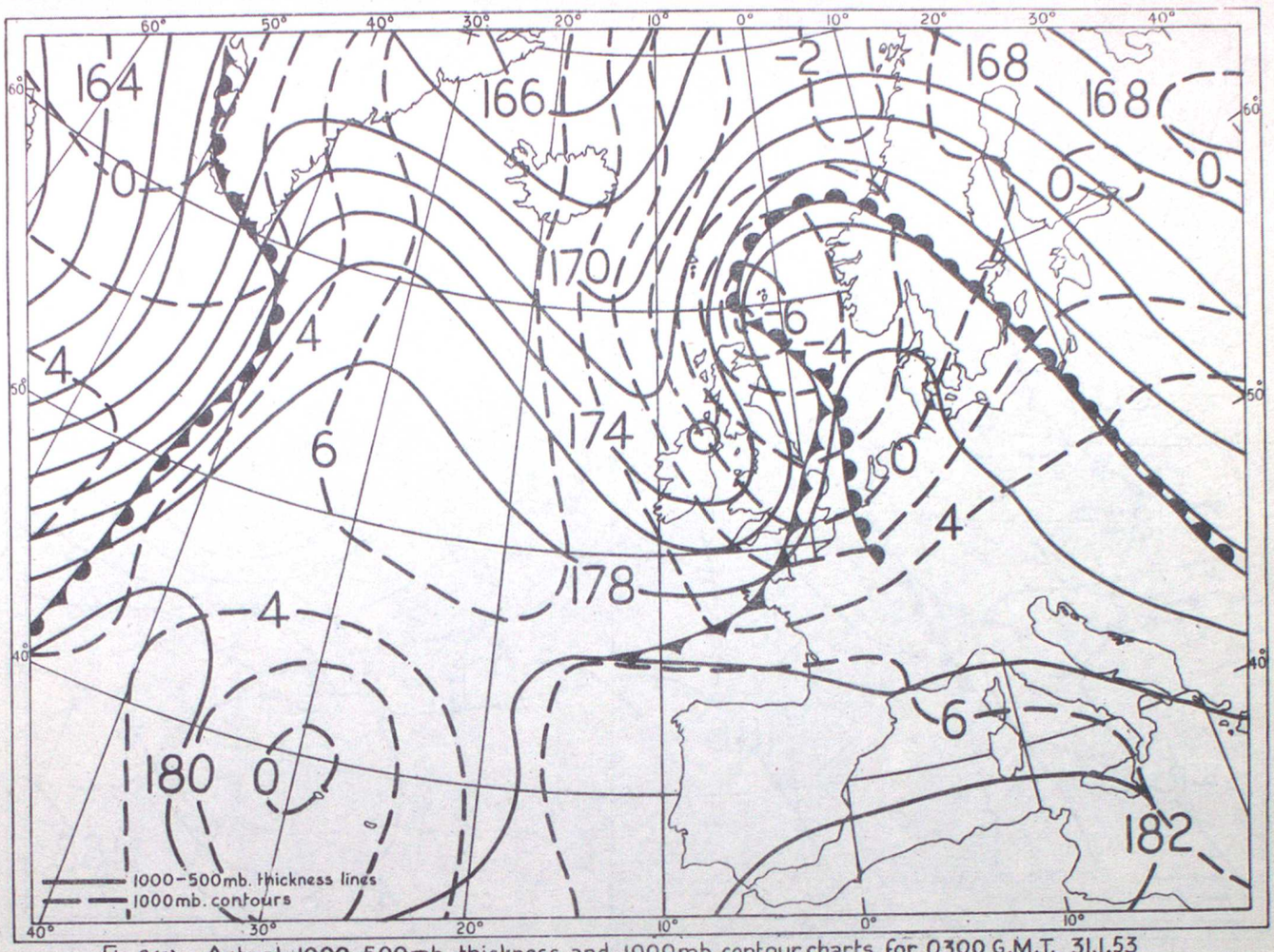

Fig.8(e) Actual 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 31.1.53

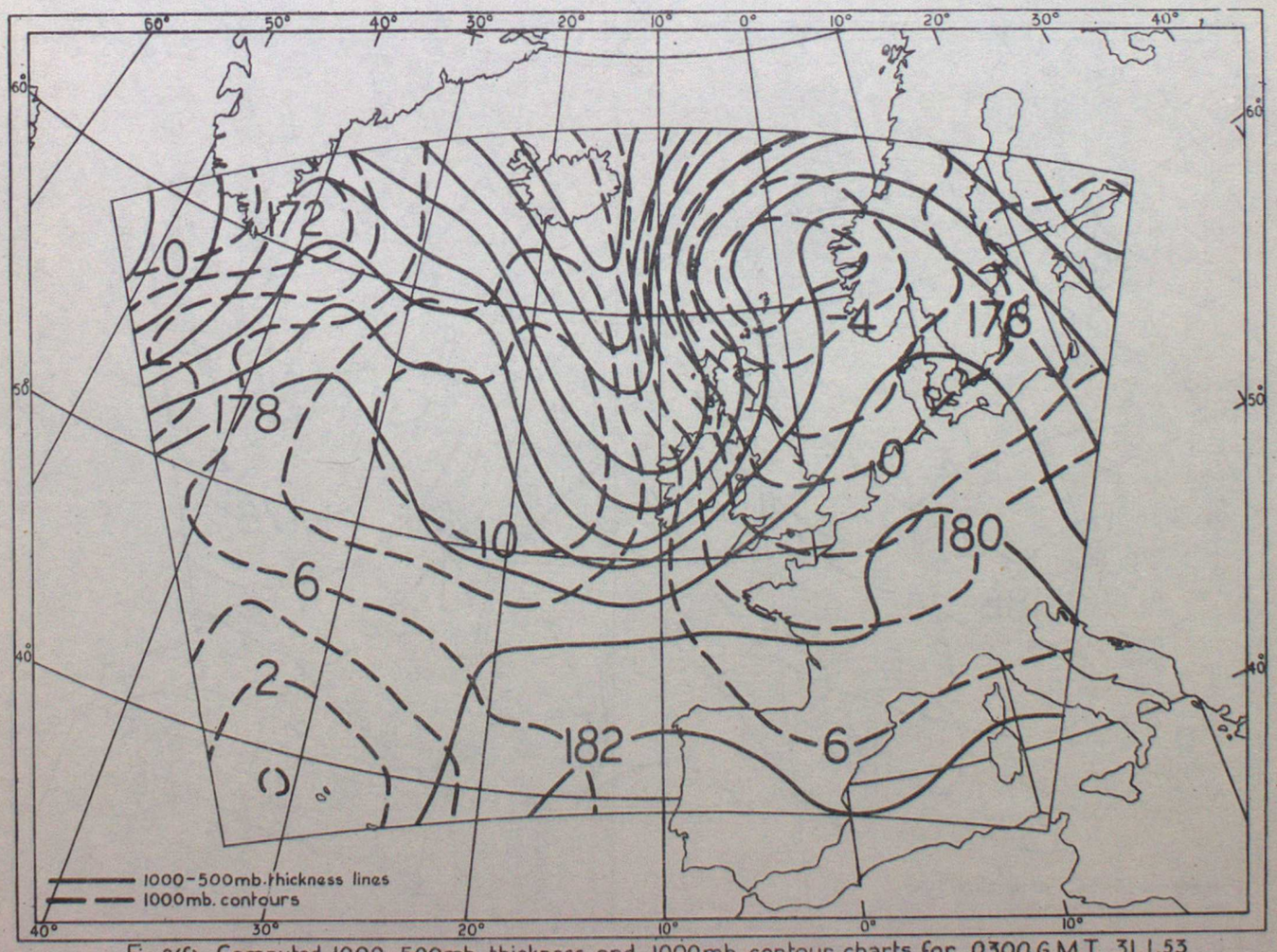

Fig.8(f) Computed 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 31.1.53

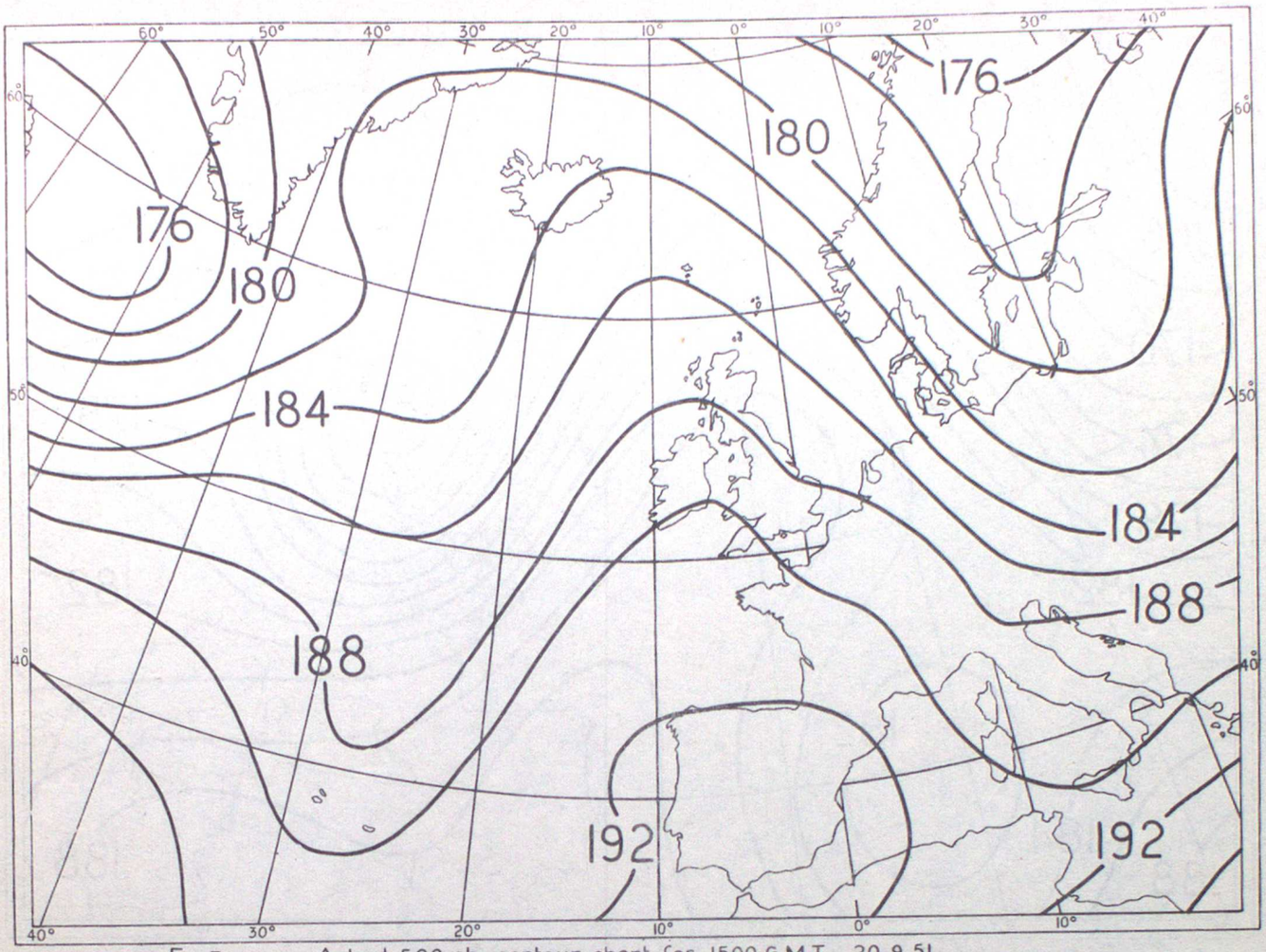

Fig.3(g) Actual 500mb. contour chart for 1500 G.M.T. 20.9.51

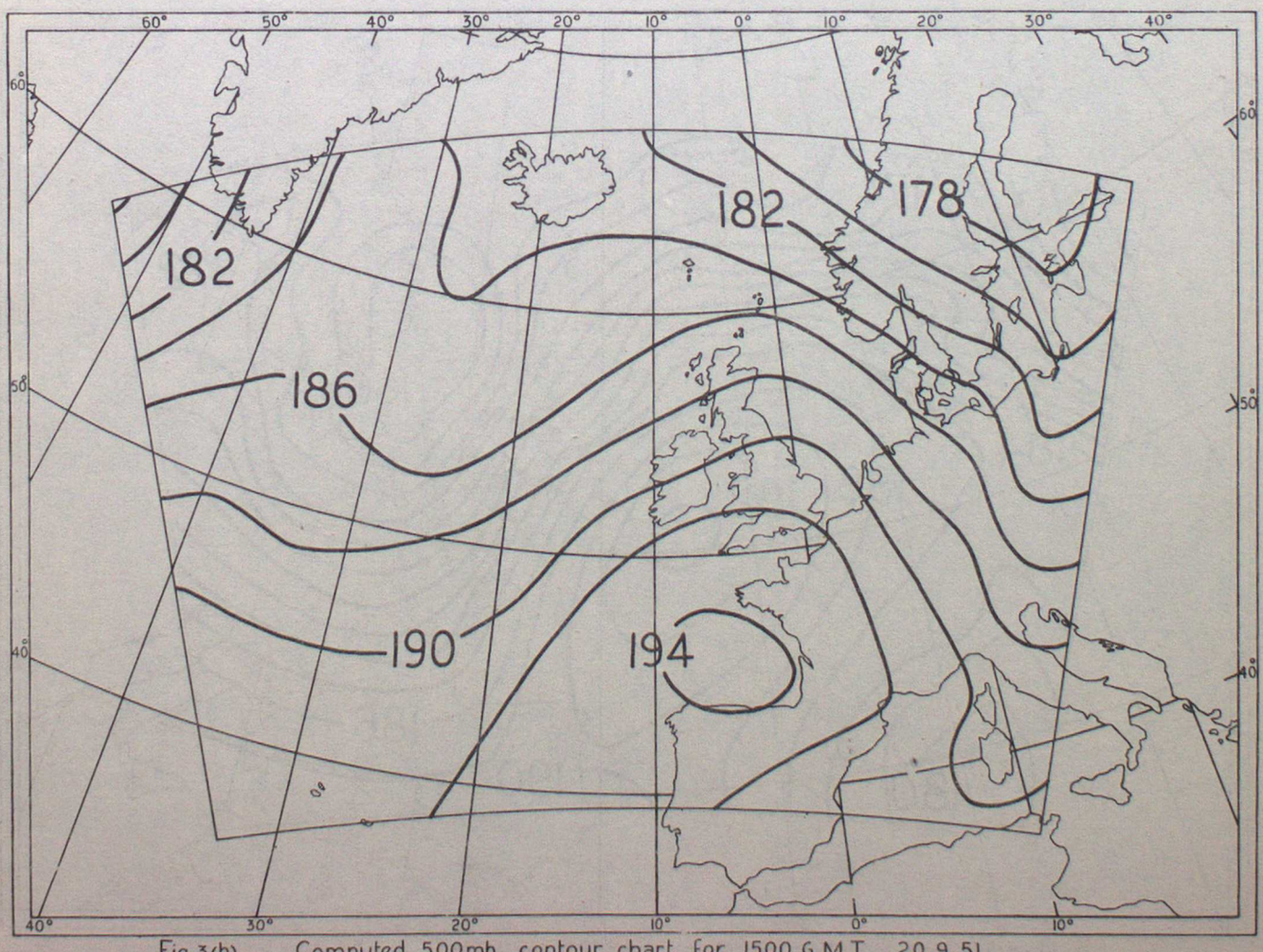

Fig.3(h) Computed 500mb. contour chart for 1500 G.M.T. 20.9.51

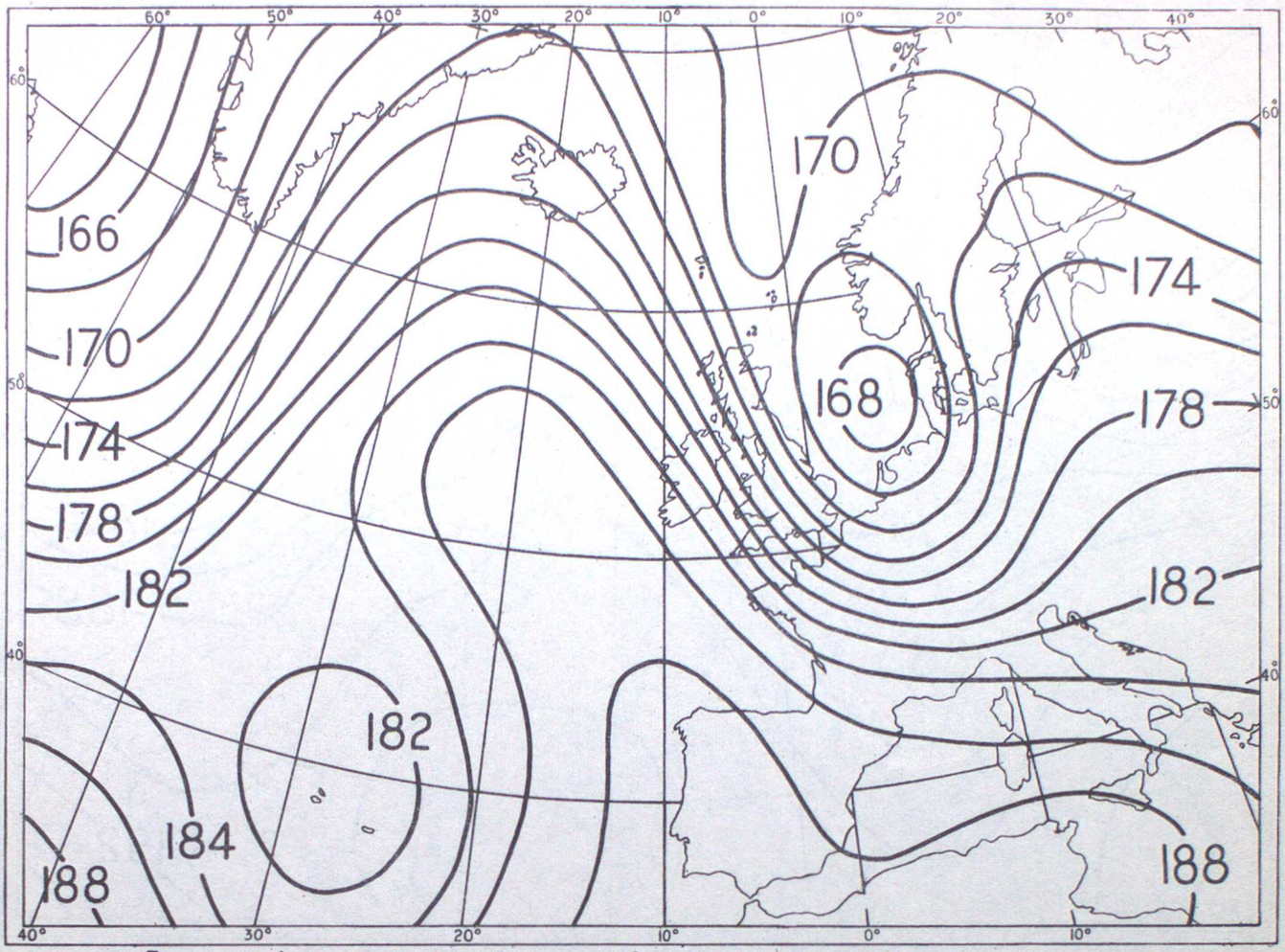

Fig.8(g) Actual 500mb. contour chart for 1500 G.M.T. 31.1.53

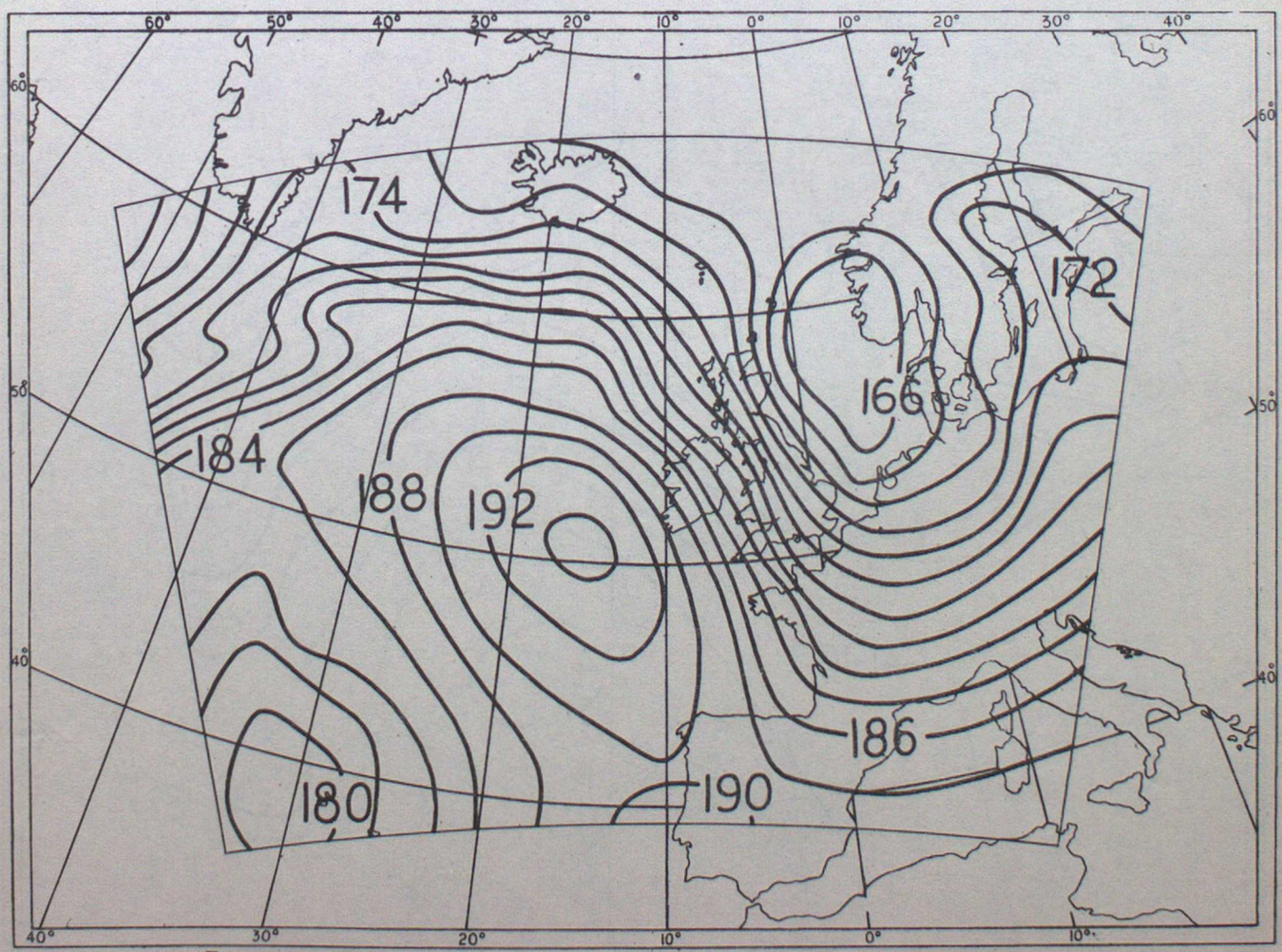

Fig.8(h) Computed 500mb. contour chart for 1500 G.M.T. 31.1.53

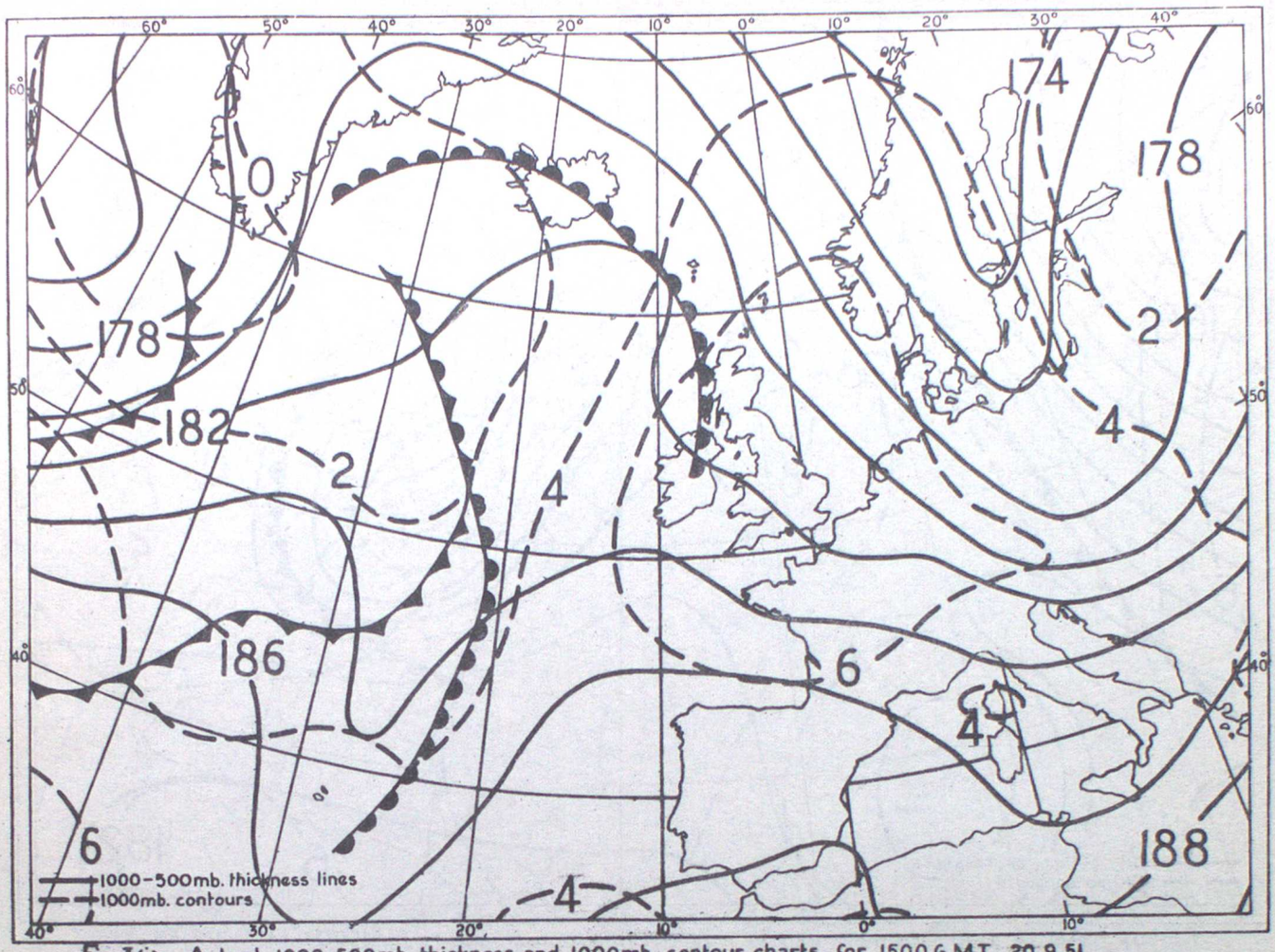

Fig.3(i) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 20.9.51

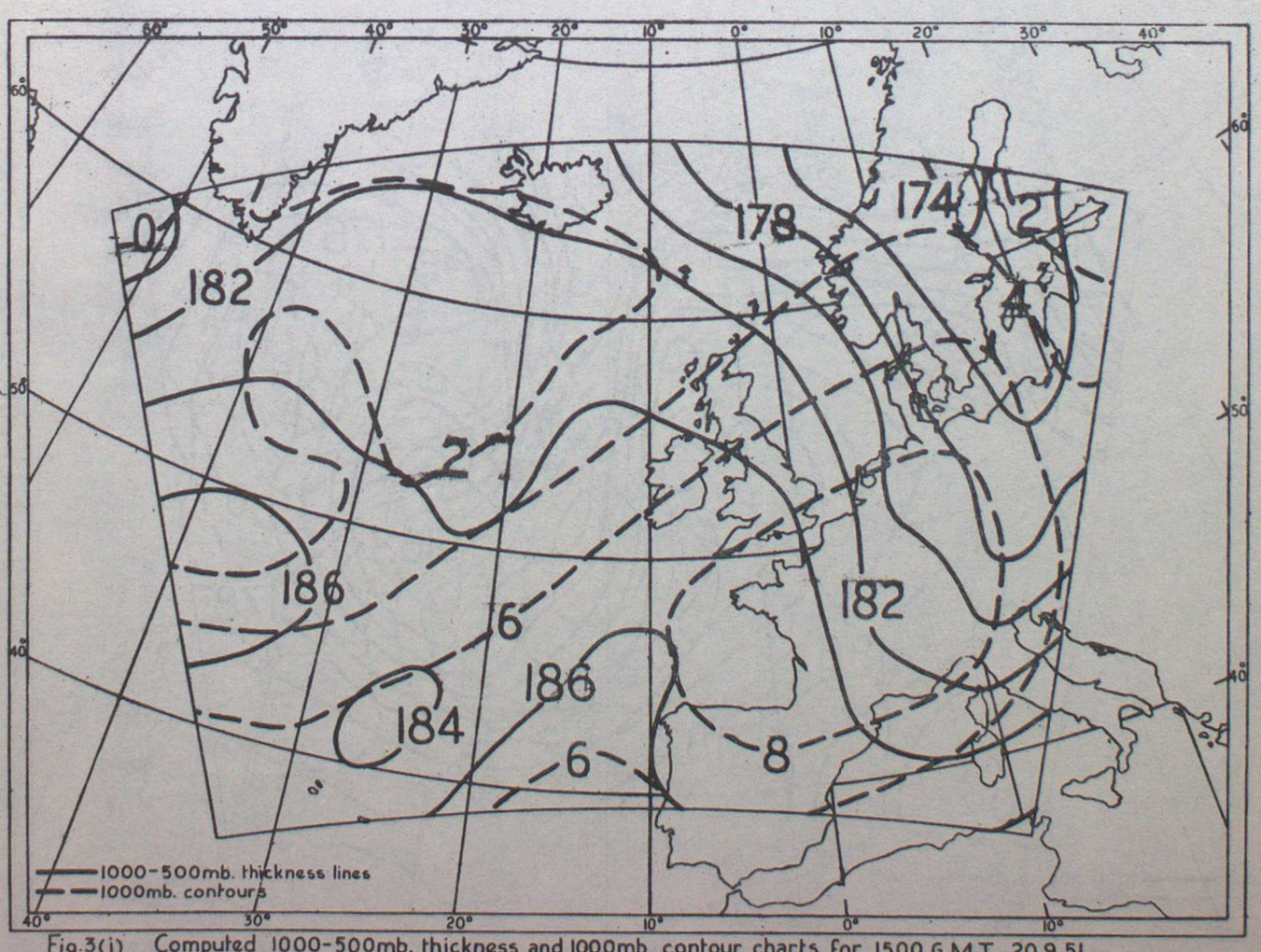

Fig.3(j) Computed 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 20.9.51

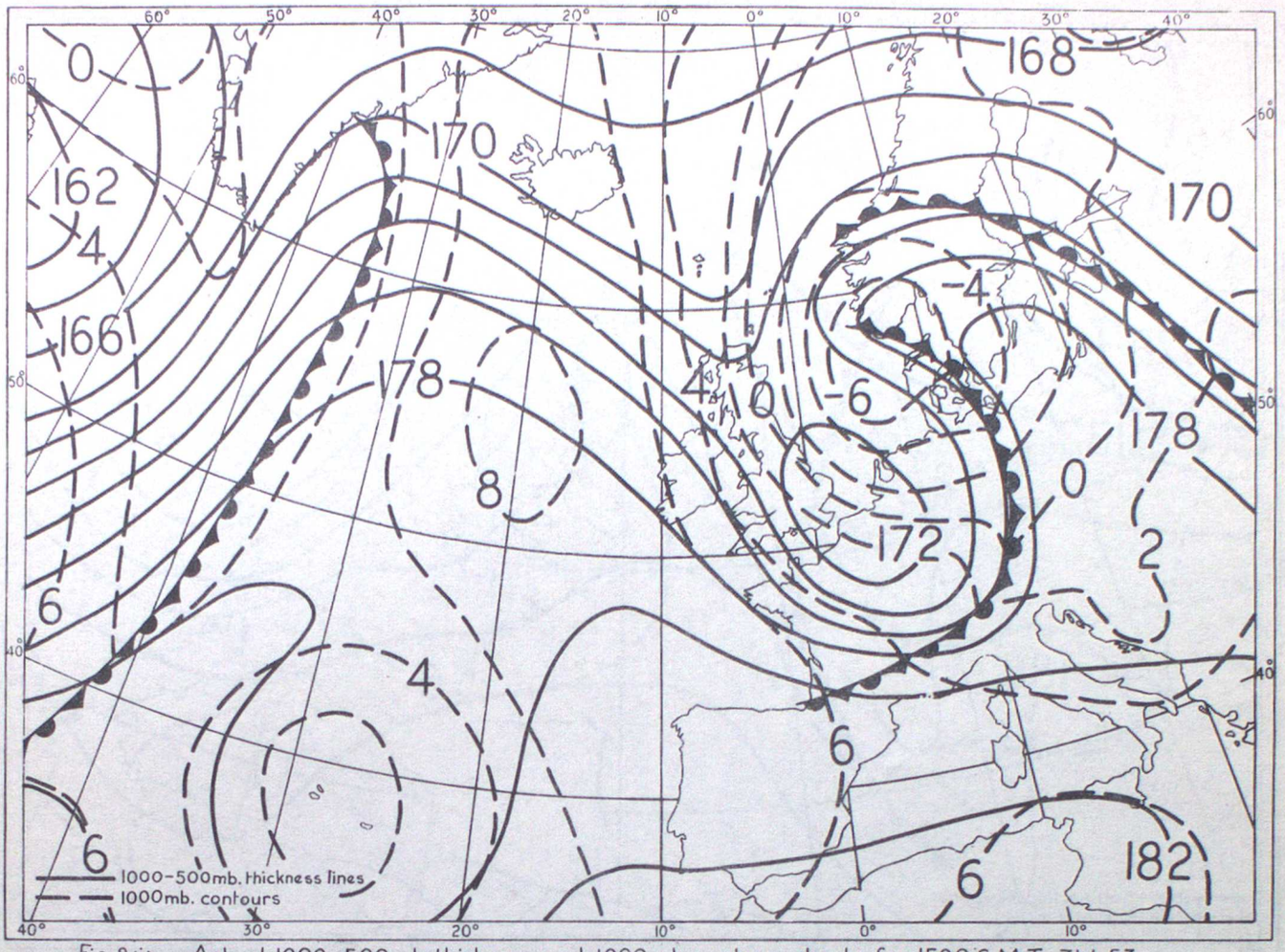

Fig.8(i) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 31.1.53

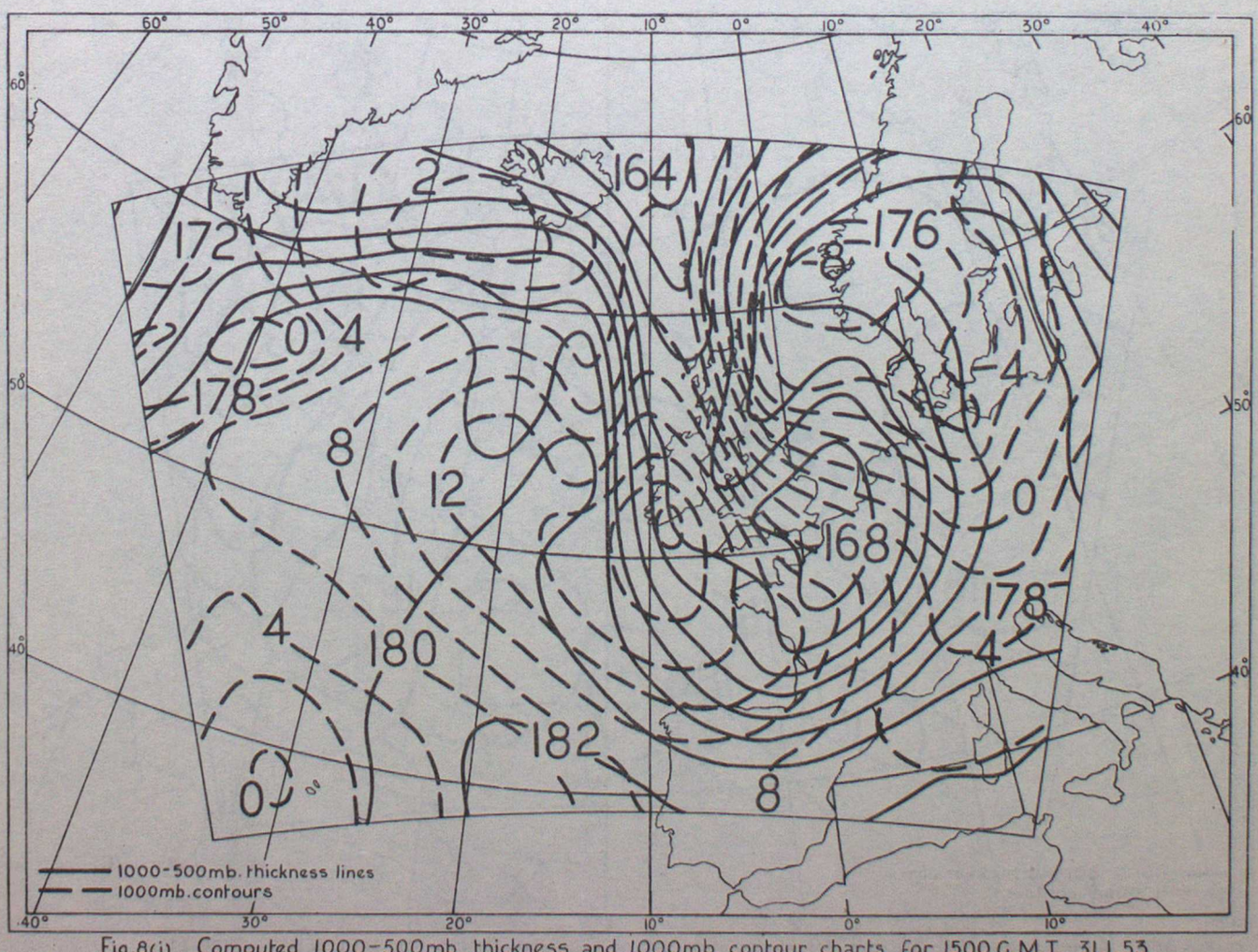

Fig.8(j) Computed 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 31.1.53

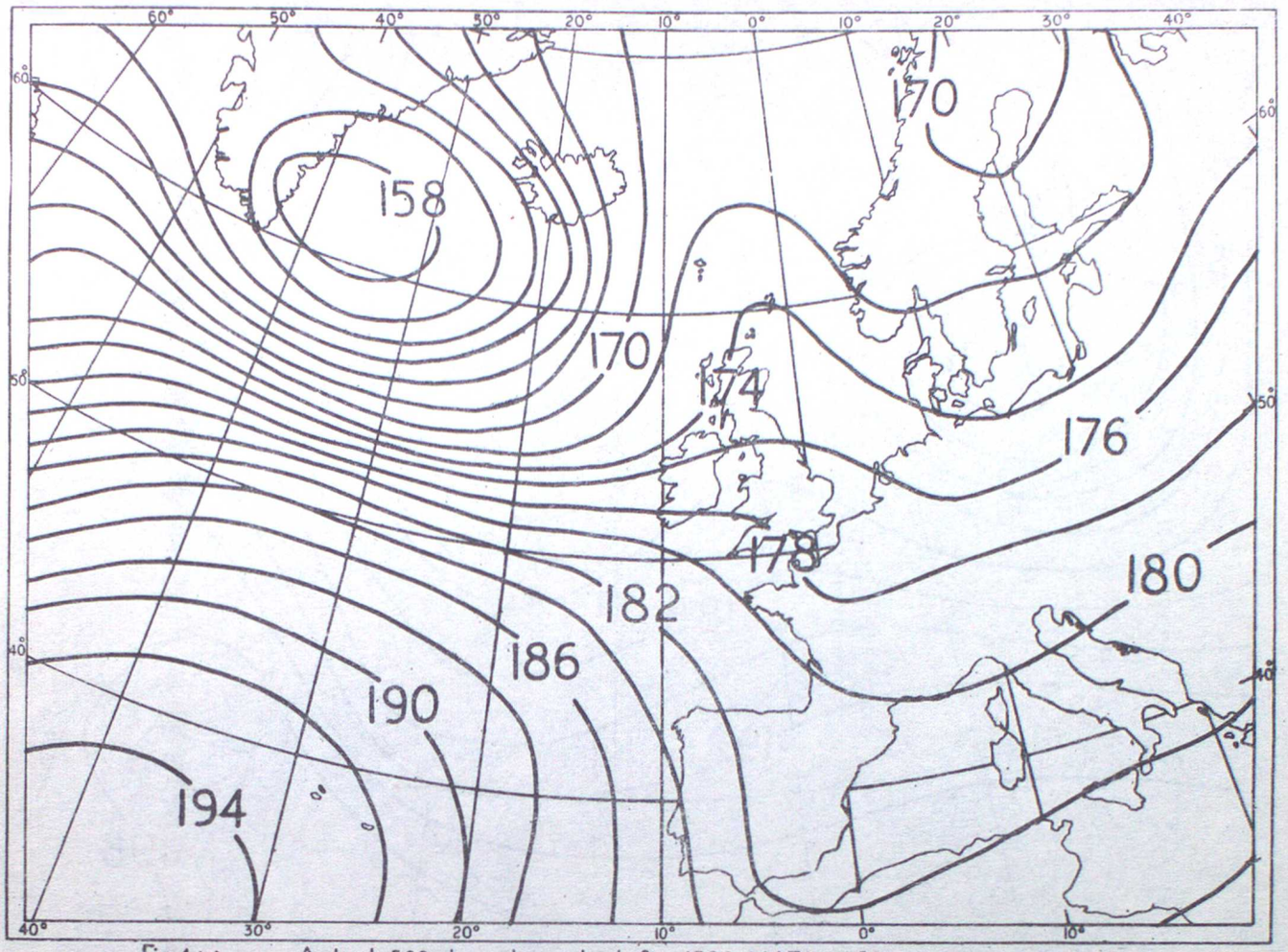

Fig.4(a) Actual 500mb. contour chart for 1500 G.M.T. 30.1.52

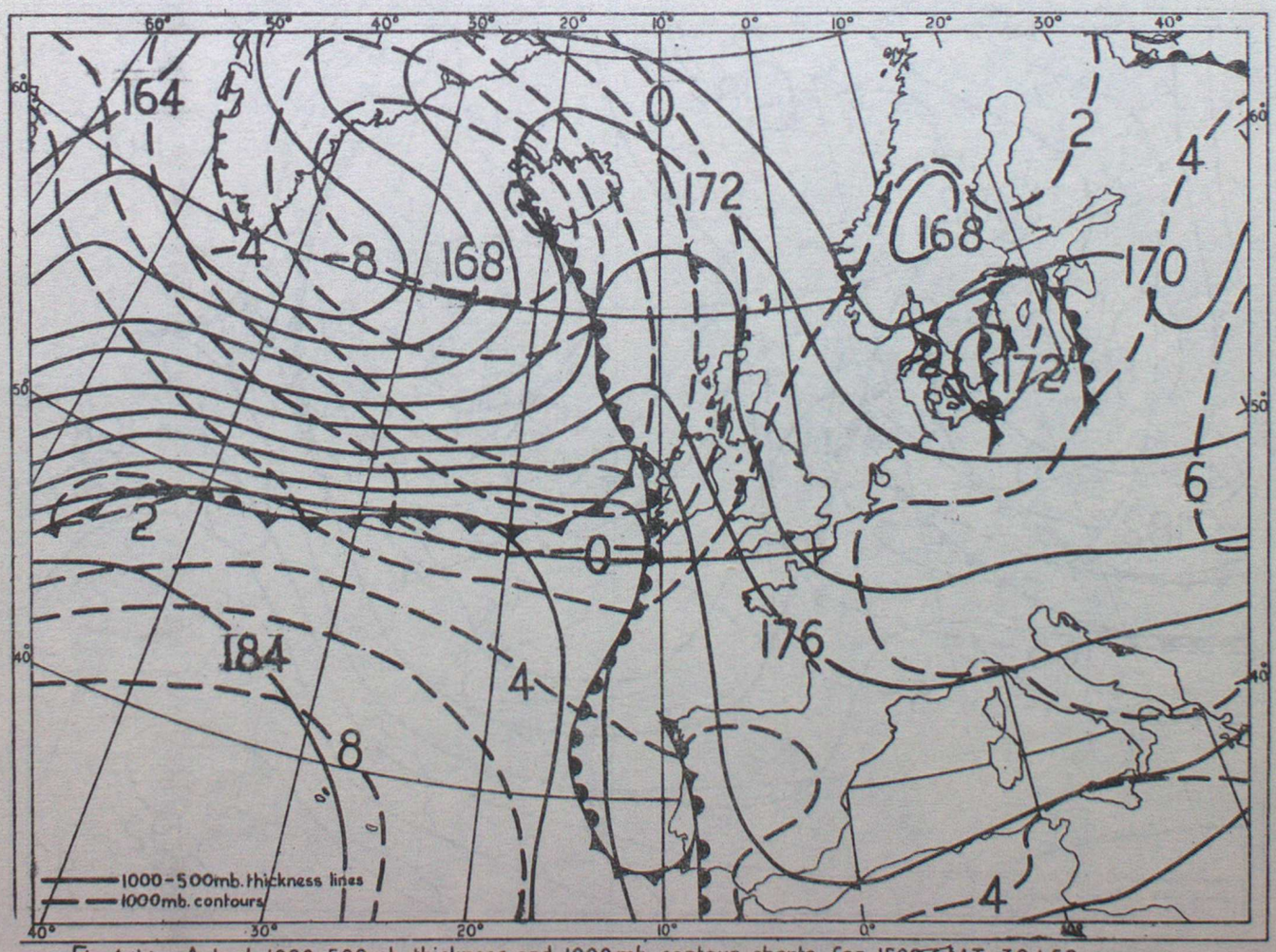

Fig.4(b) Actual 1000-500mb. thickness and 1000 mb. contour charts for 1500 G.M.T. 30.1.52

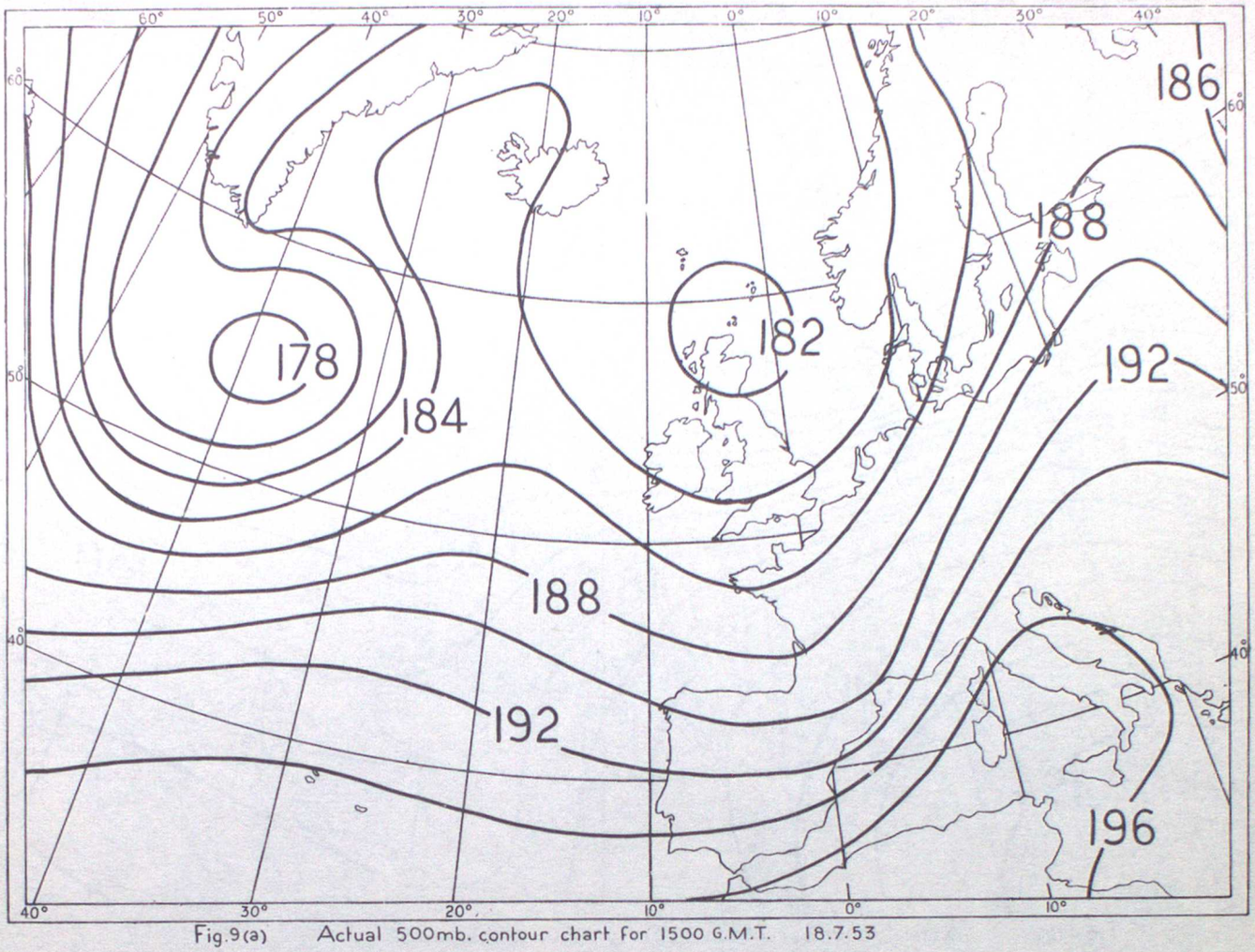

Fig.9(a) Actual 500mb. contour chart for 1500 G.M.T. 18.7.53

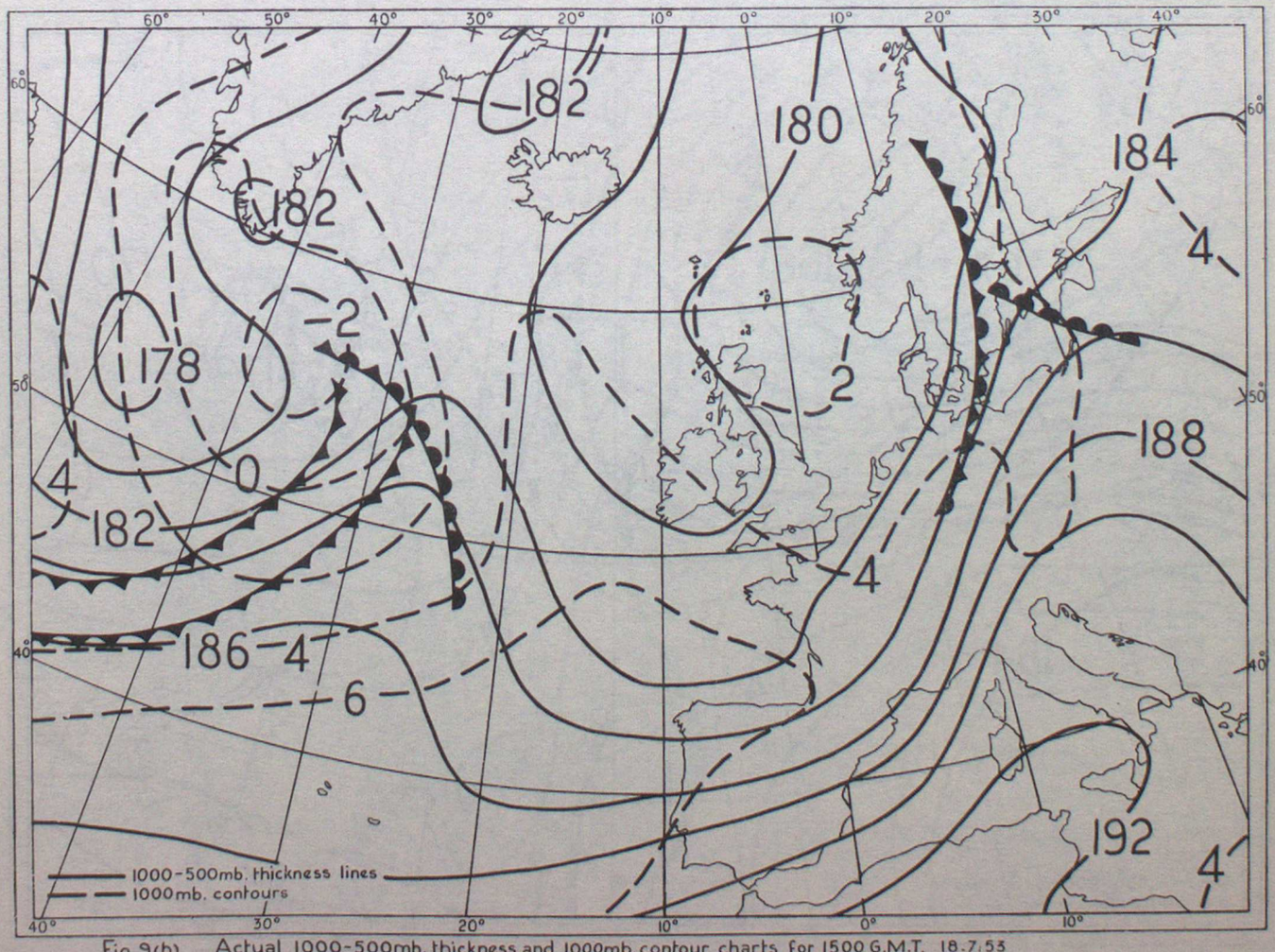

Fig.9(b) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 18.7.53

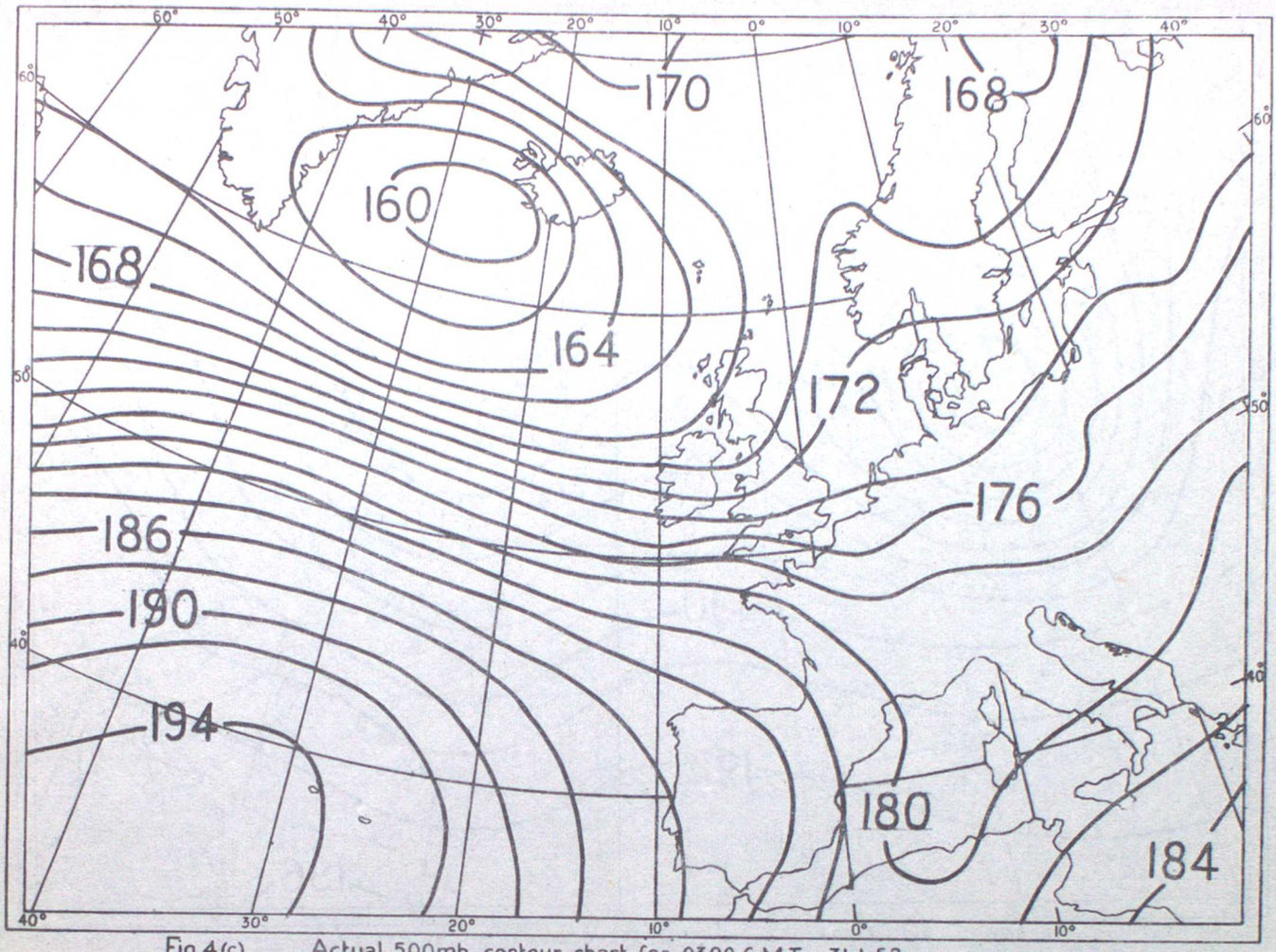

Fig.4(c) Actual 500mb. contour chart for 0300 G.M.T. 31.1.52

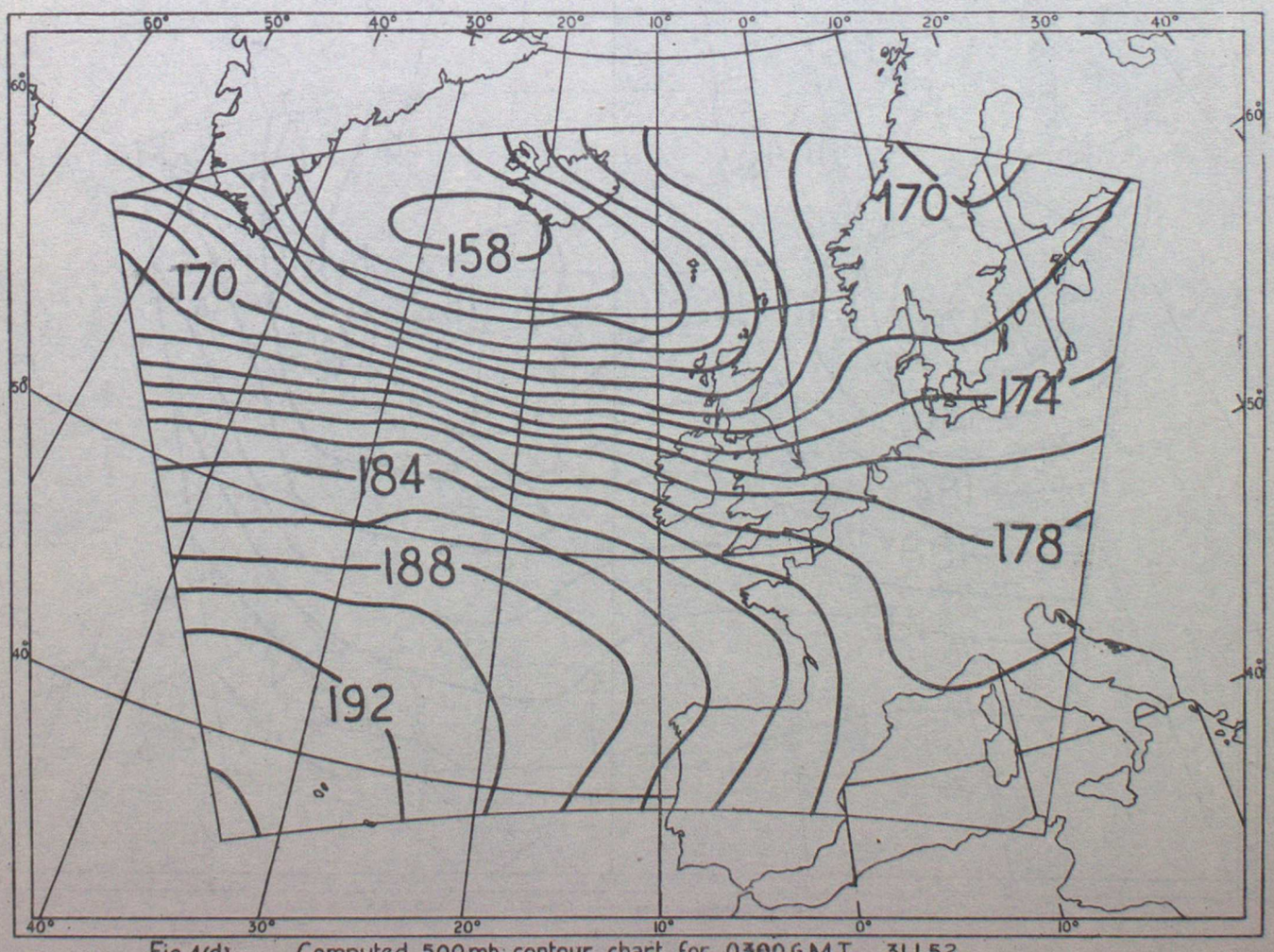

Fig.4(d) Computed 500mb. contour chart for 0300 G.M.T. 31.1.52

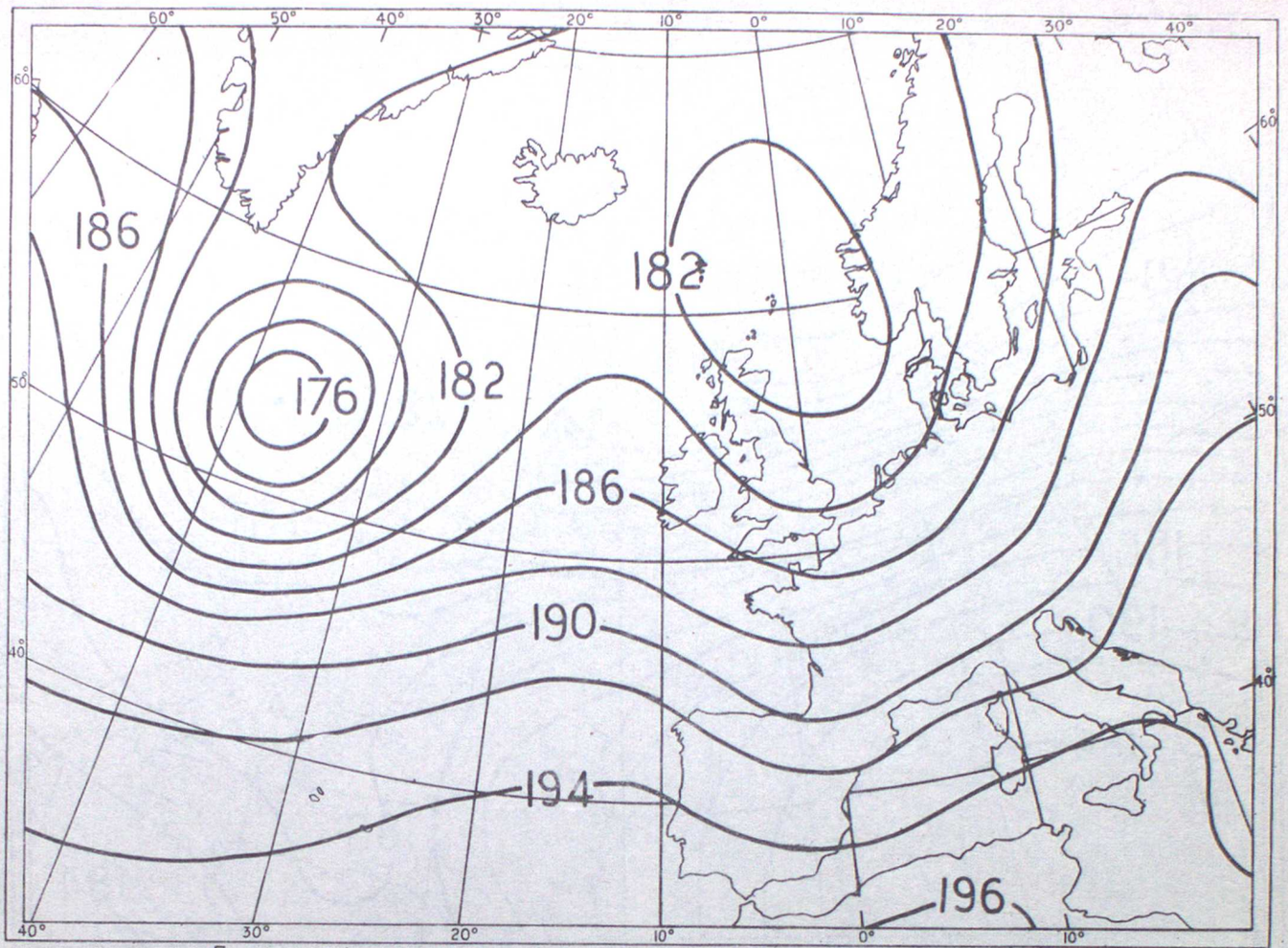

Fig.9(c) Actual 500mb. contour chart for 0300 G.M.T. 19.7.53

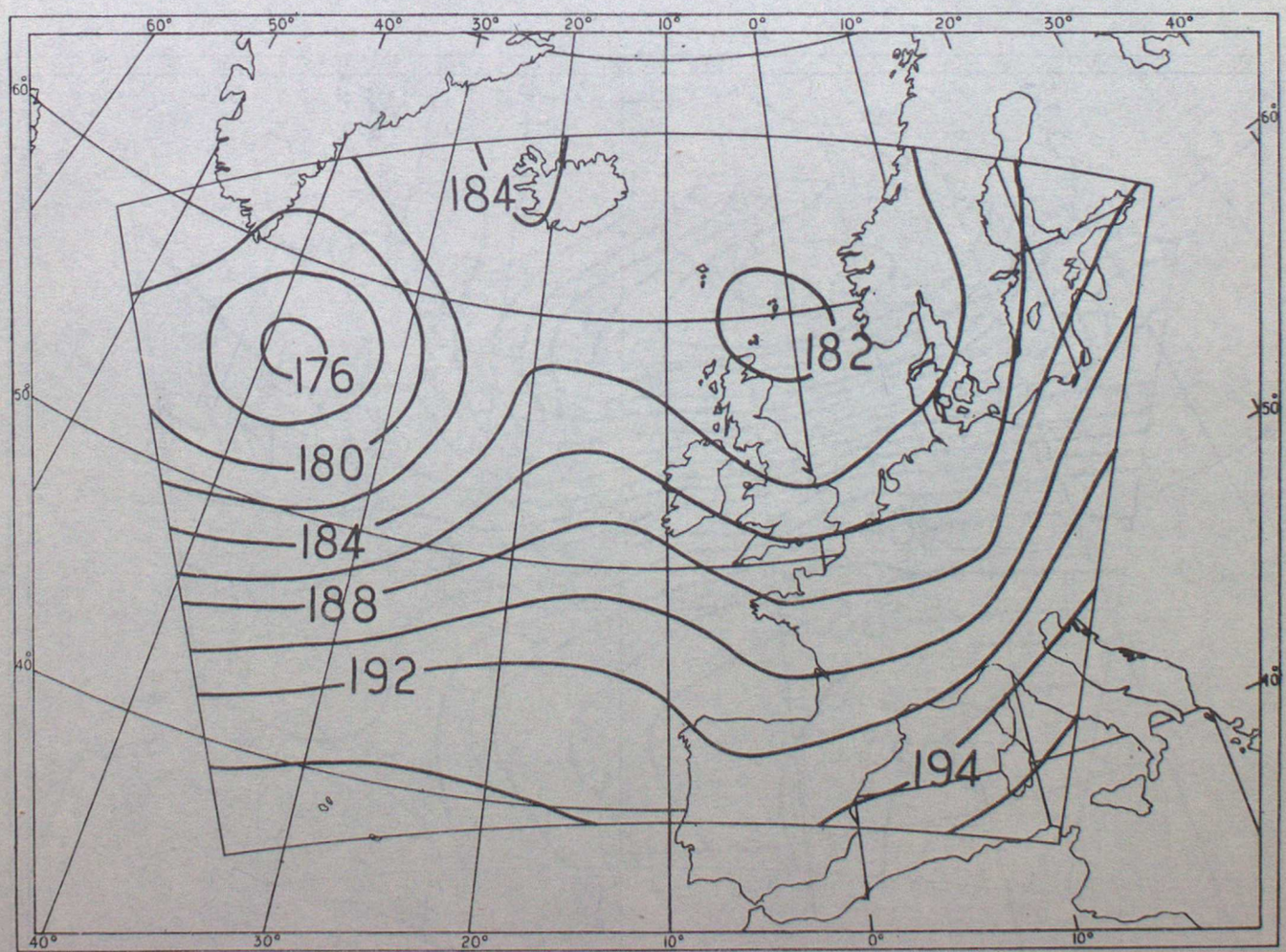

Fig.9(d) Computed 500mb. contour chart for 0300 G.M.T. 19.7.53

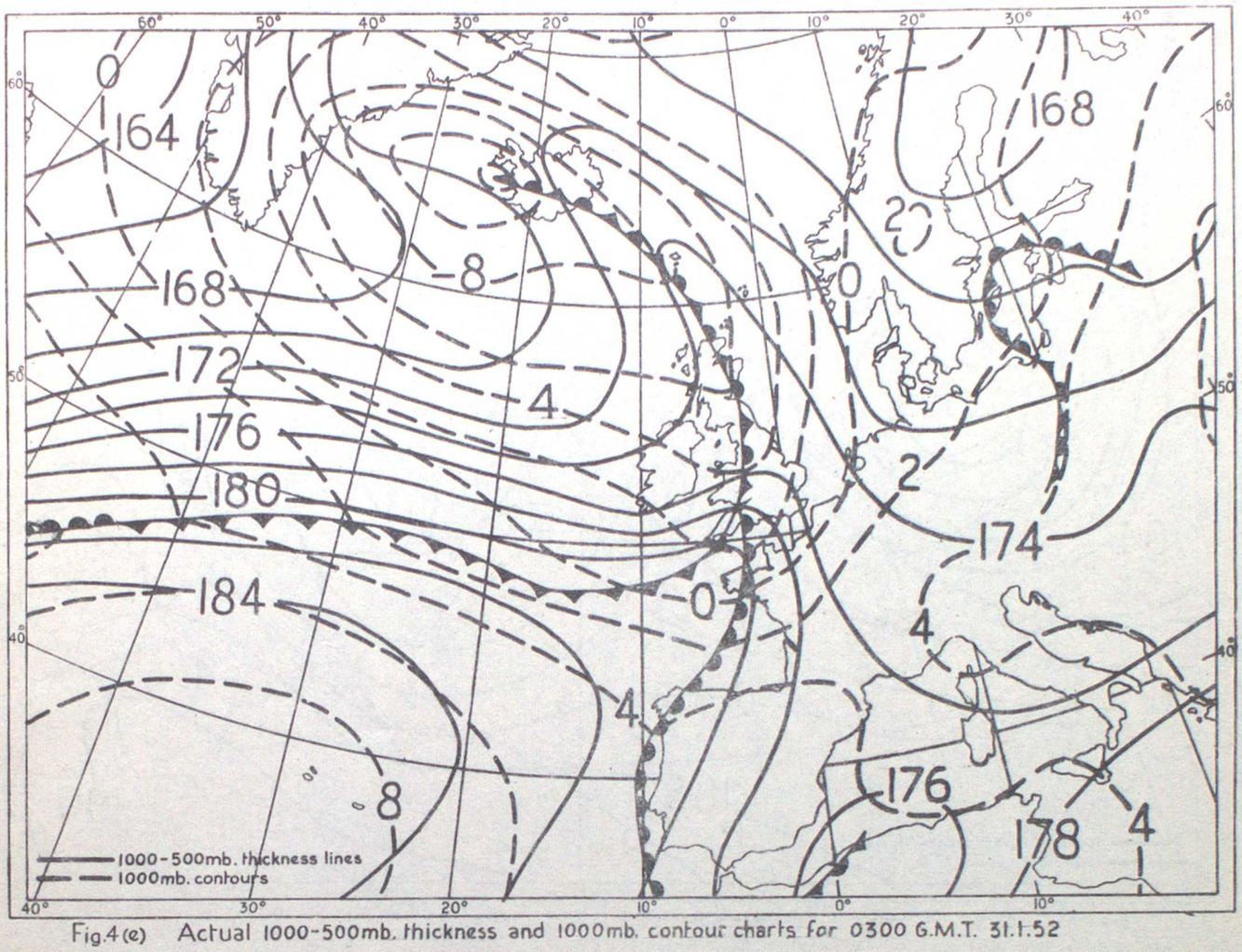

Fig.4(e) Actual 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 31.1.52

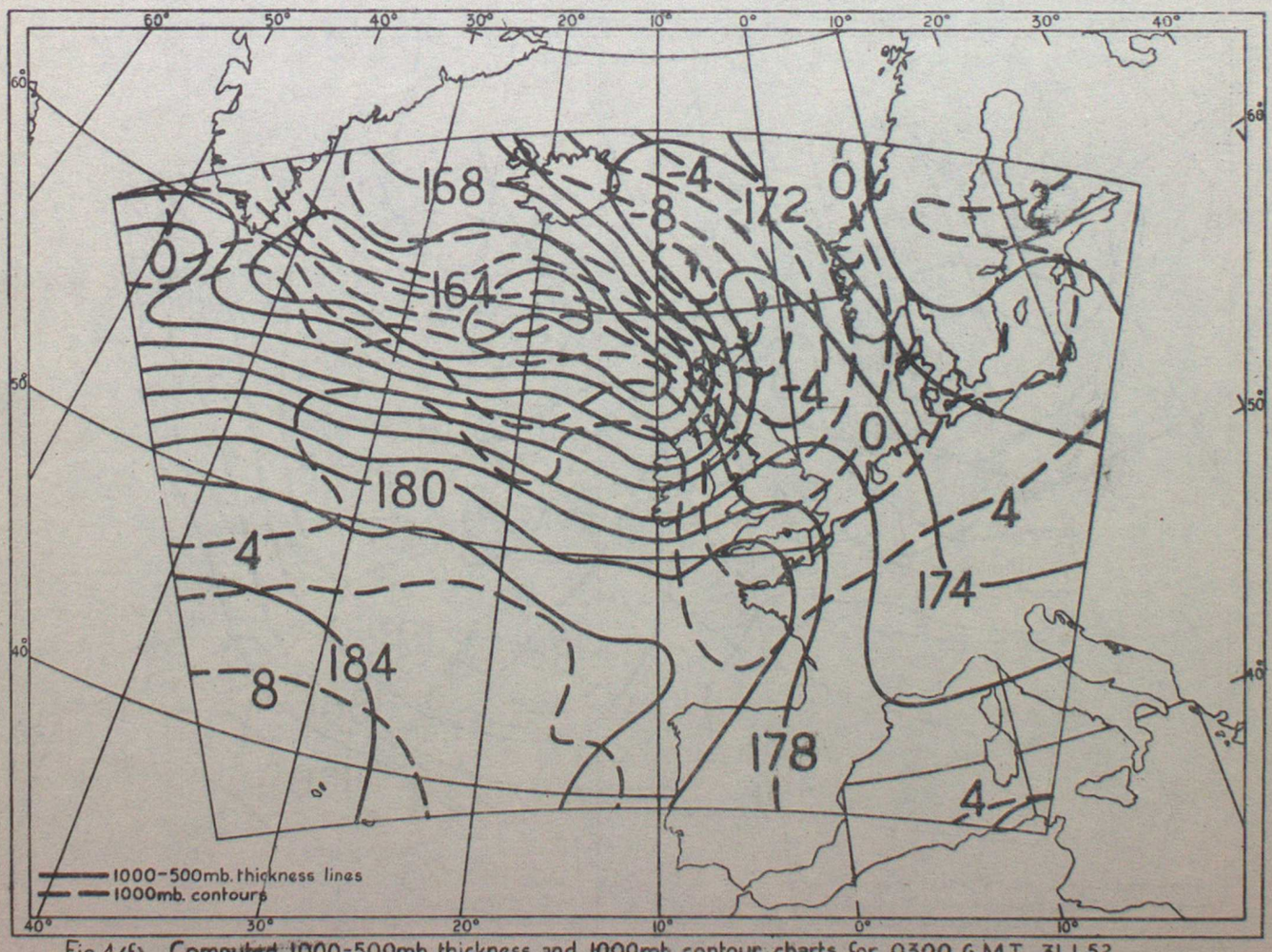

Fig.4(f) Computed 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 31.1.52

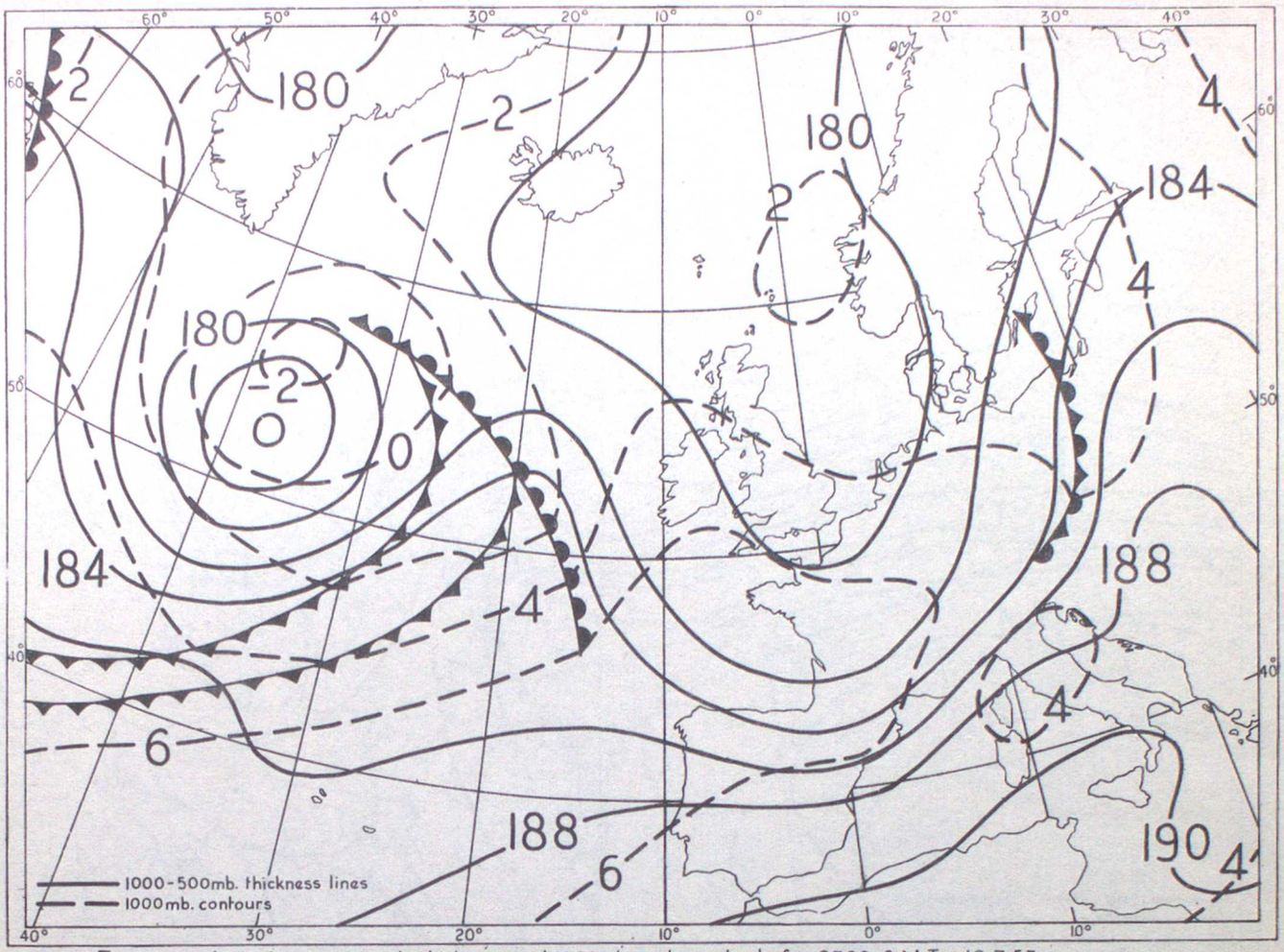

Fig.9(e) Actual 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 19.7.53

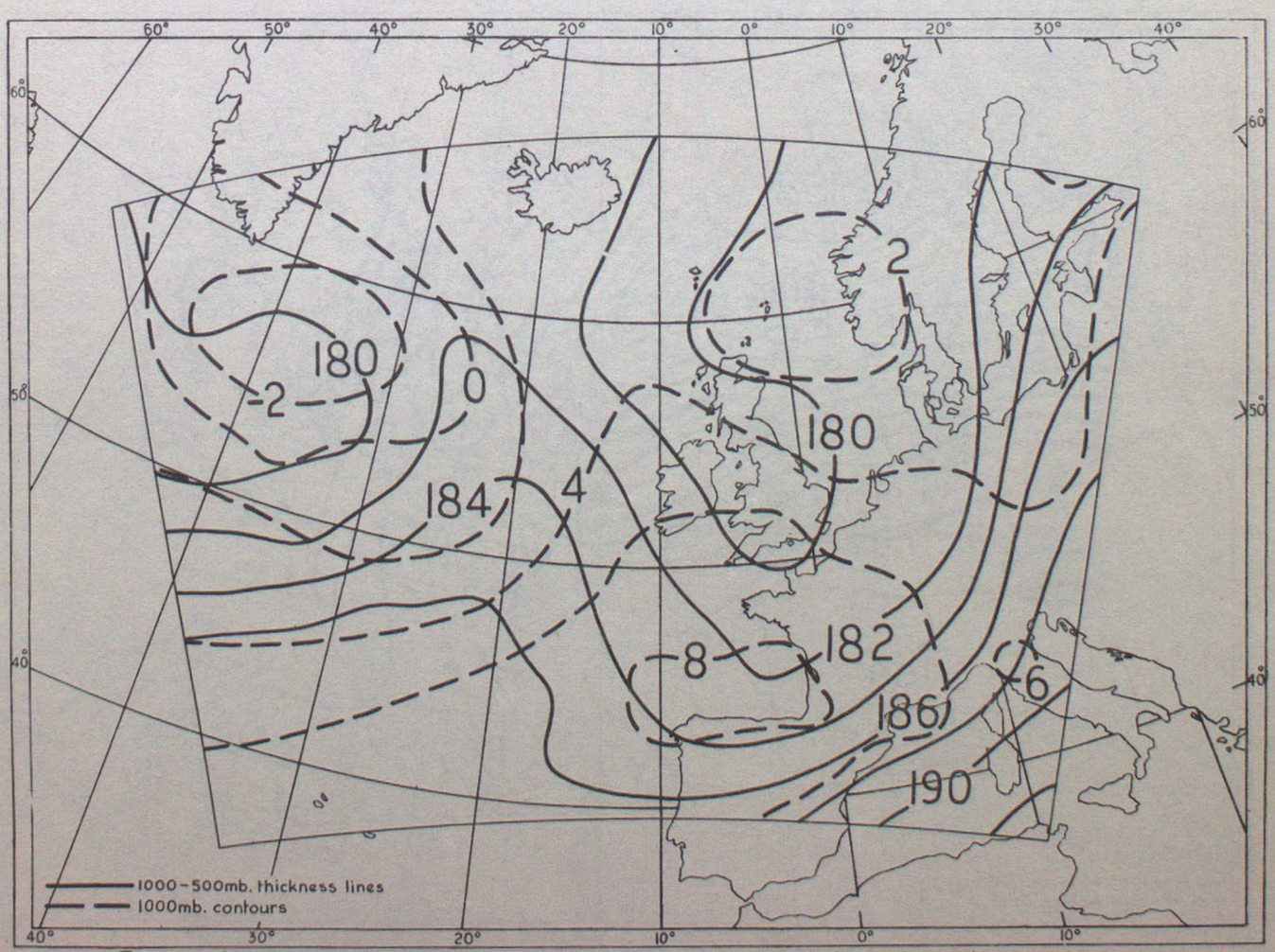

Fig.9(f) Computed 1000-500mb. thickness and 1000mb. contour charts for 0300G.M.T. 19.7.53

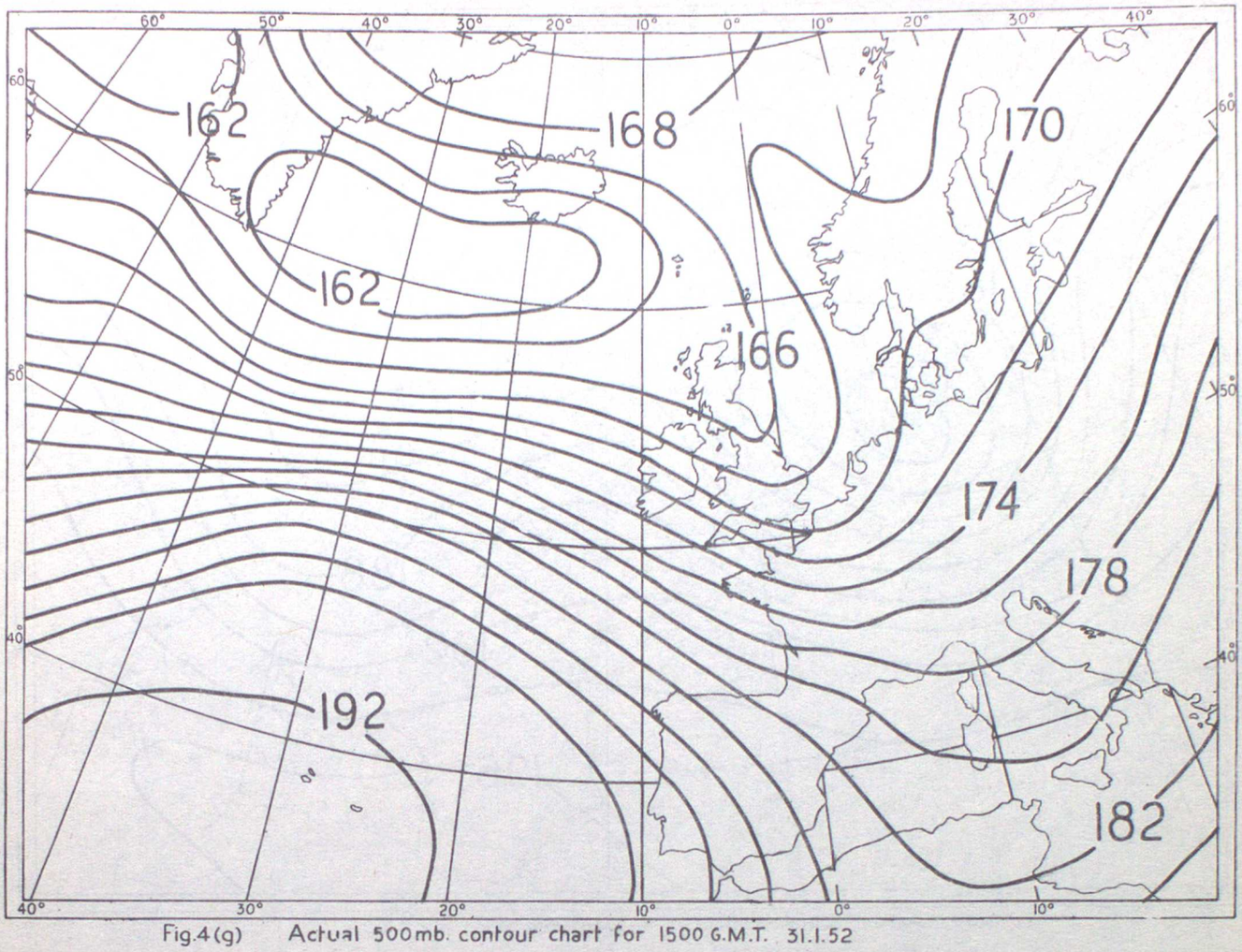

Fig.4(g) Actual 500mb. contour chart for 1500 G.M.T. 31.1.52

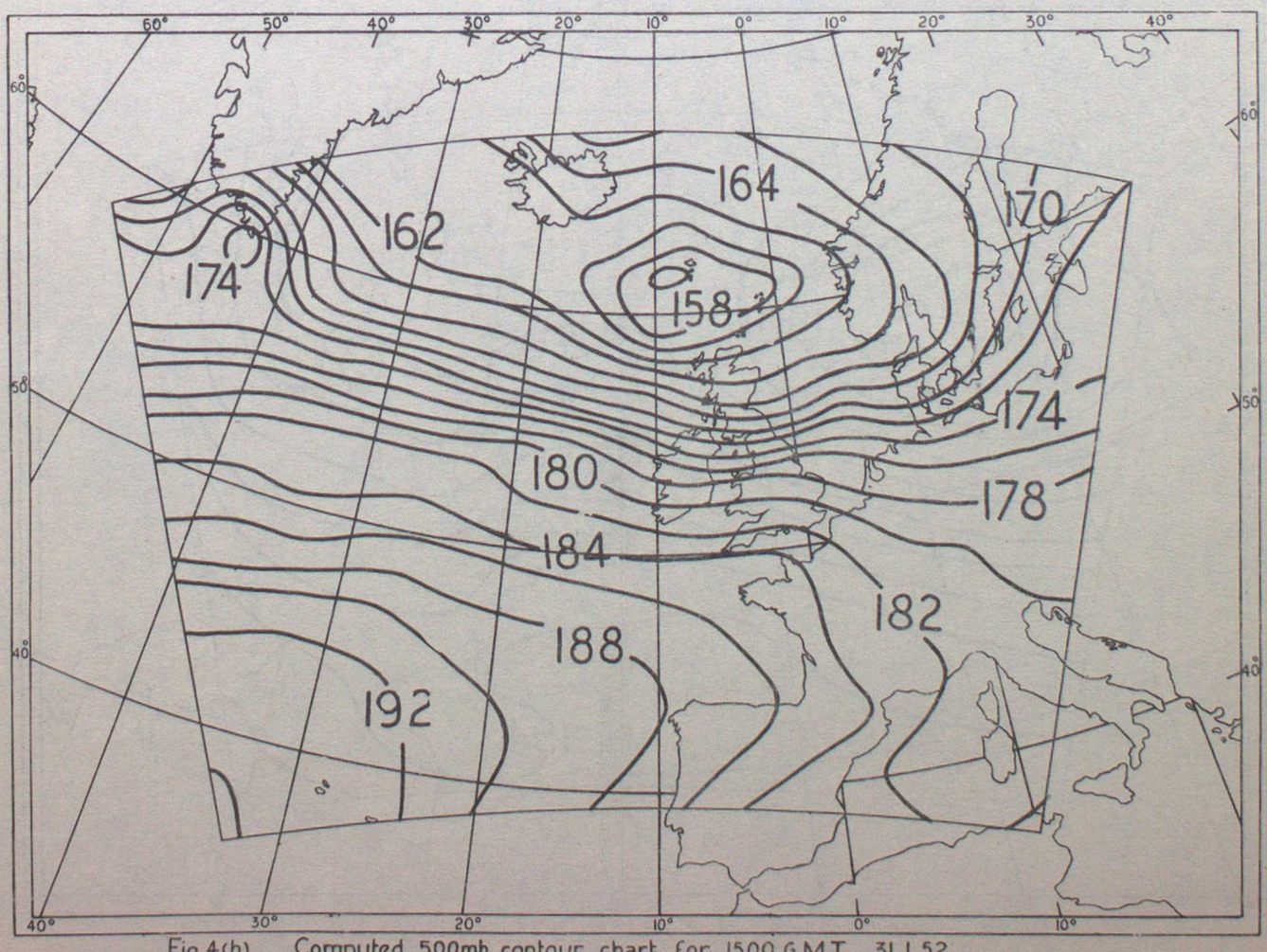

Fig.4(h) Computed 500mb. contour chart for 1500 G.M.T. 31.1.52

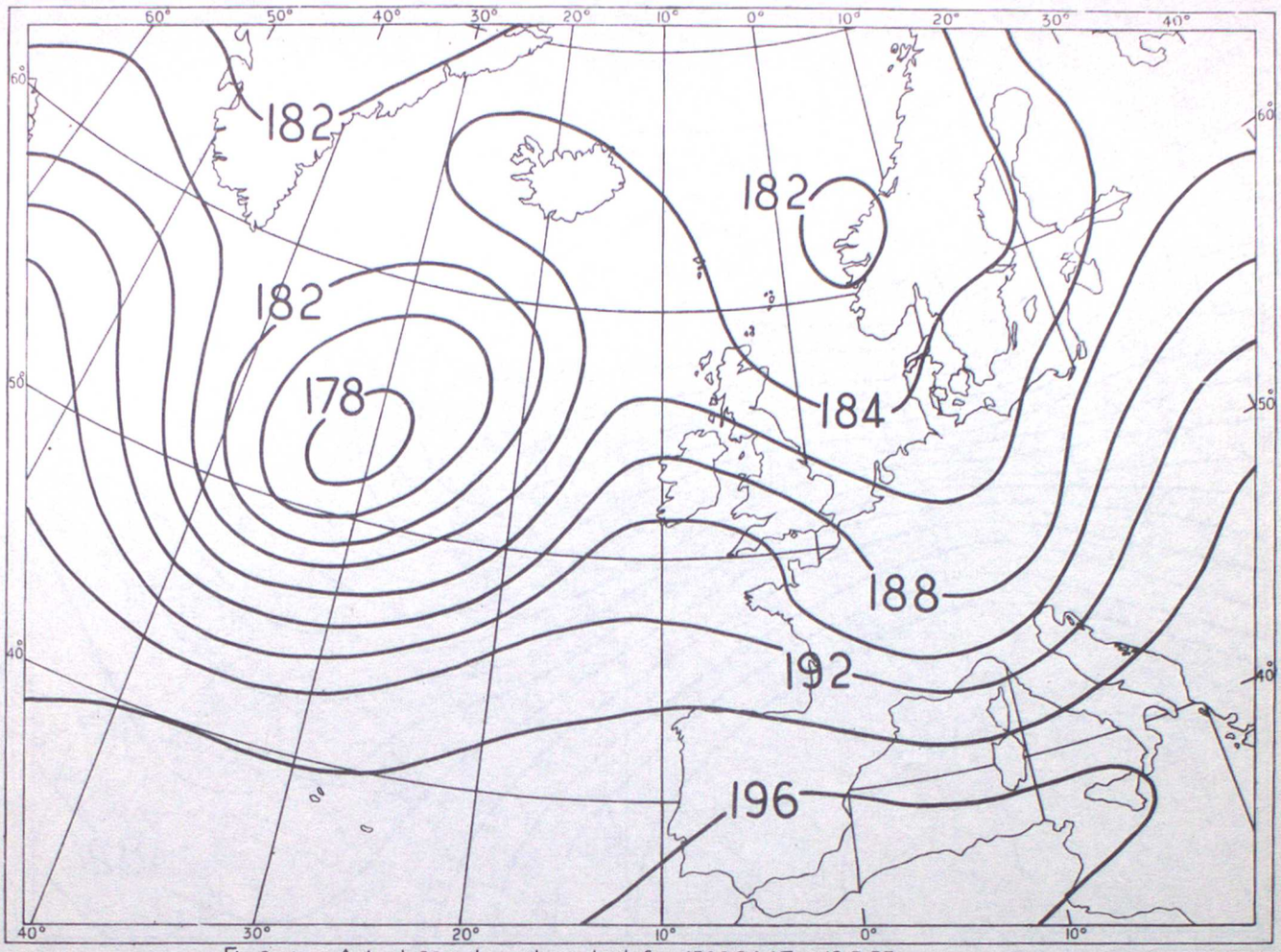

Fig. 9(g) Actual 500mb. contour chart for 1500 G.M.T. 19.7.53

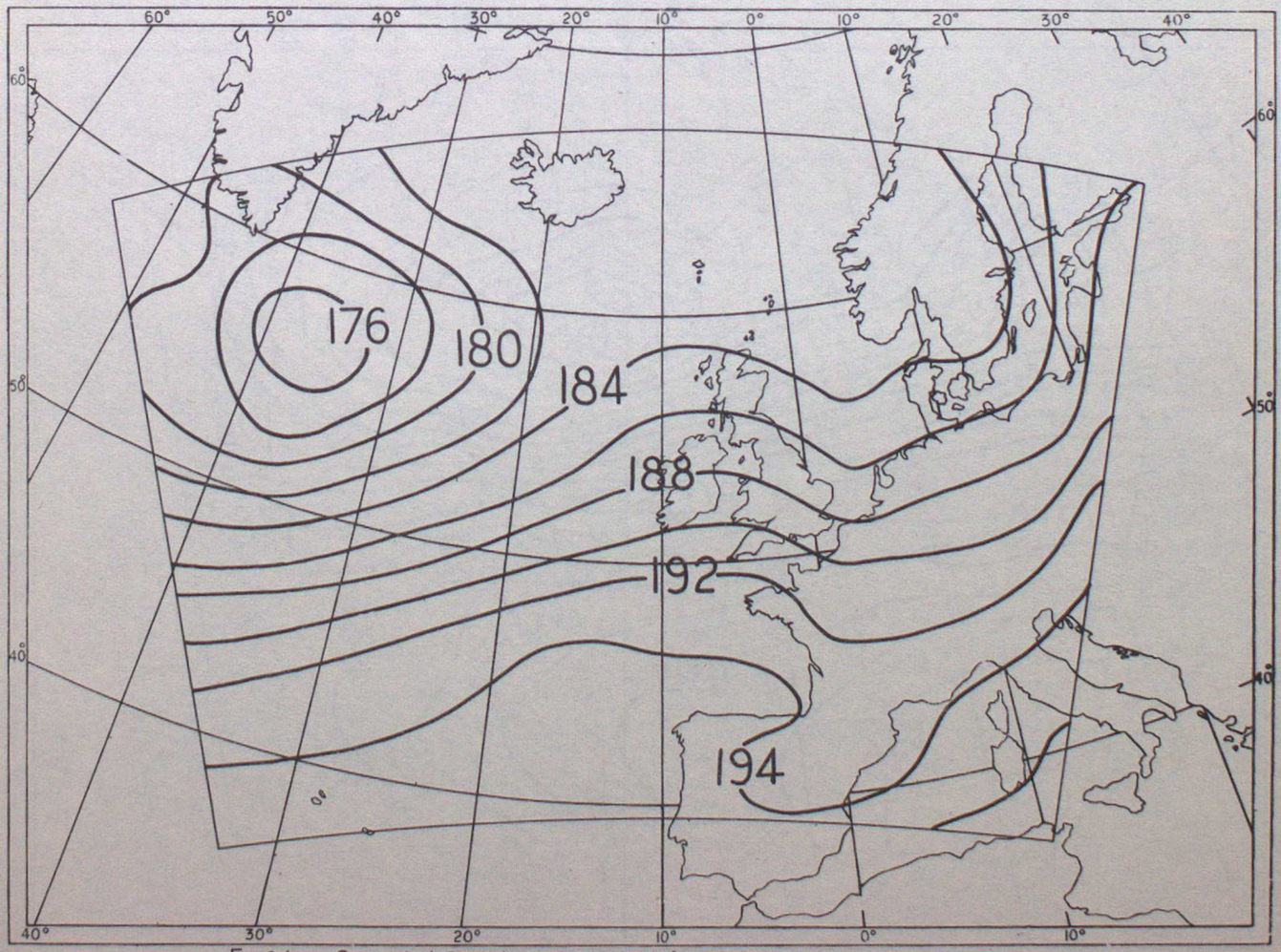

Fig. 9(h) Computed 500mb. contour chart for 1500 G.M.T. 19.7.53

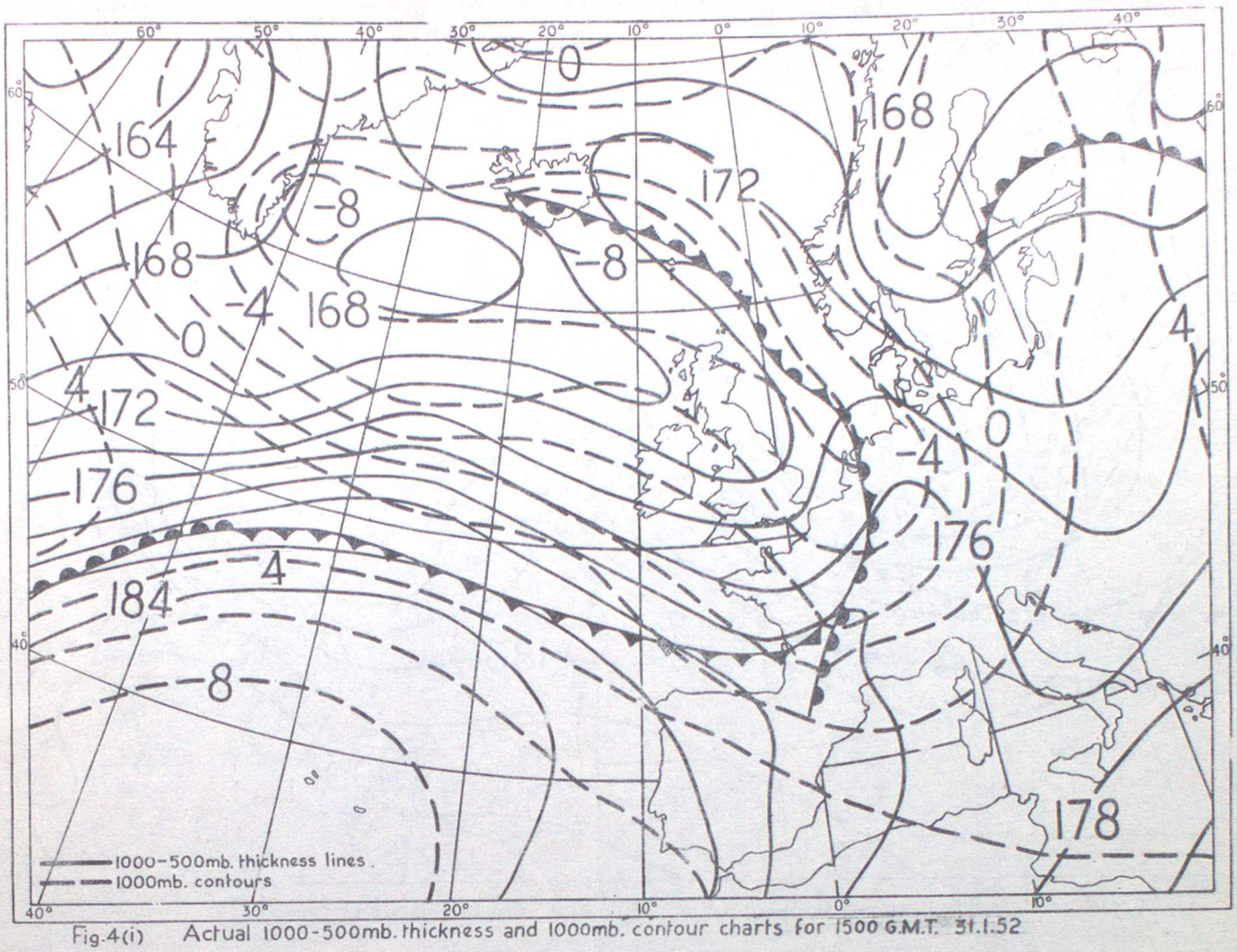

Fig.4(i) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 31.1.52

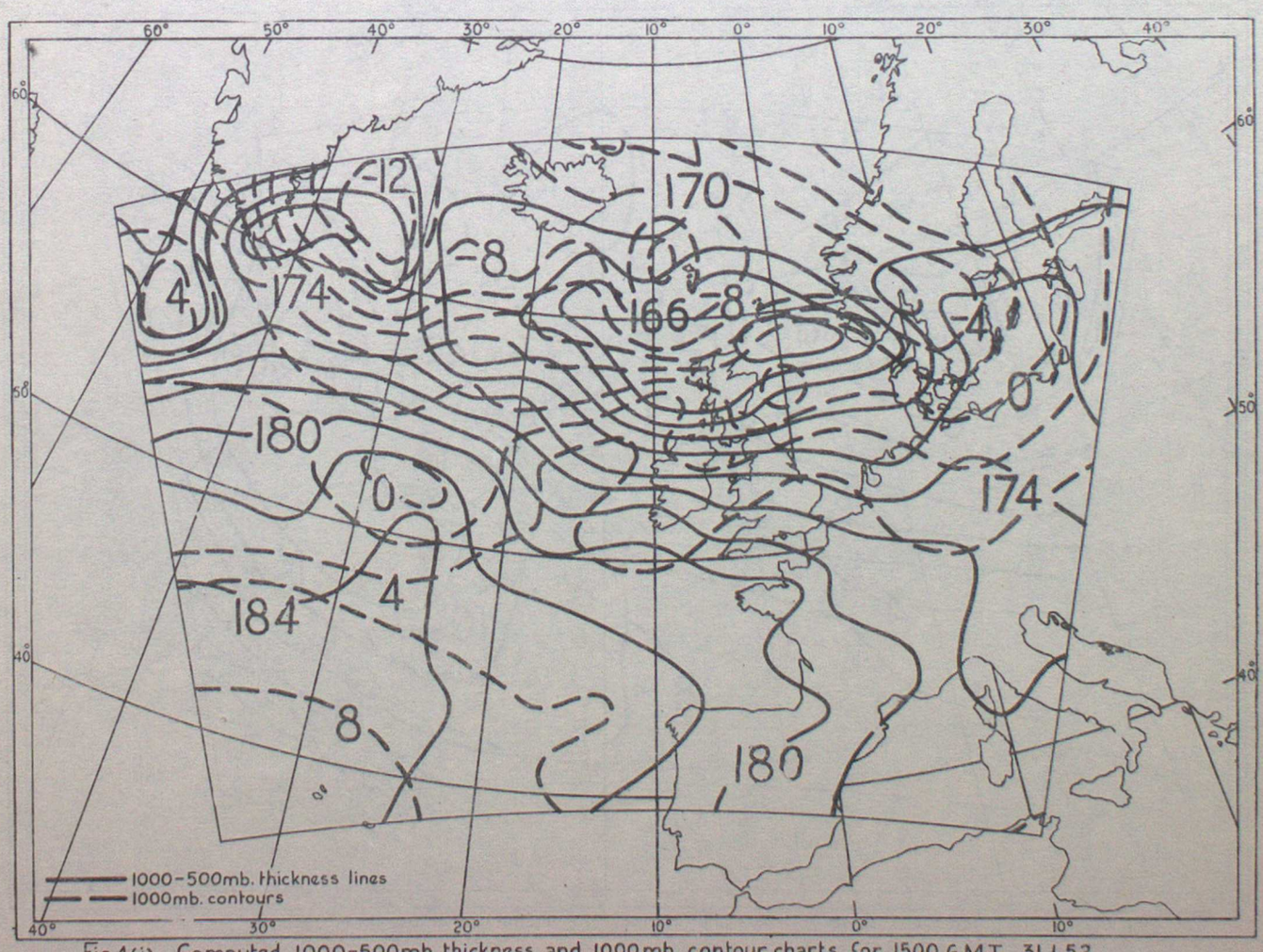

Fig.4(j) Computed 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 31.1.52

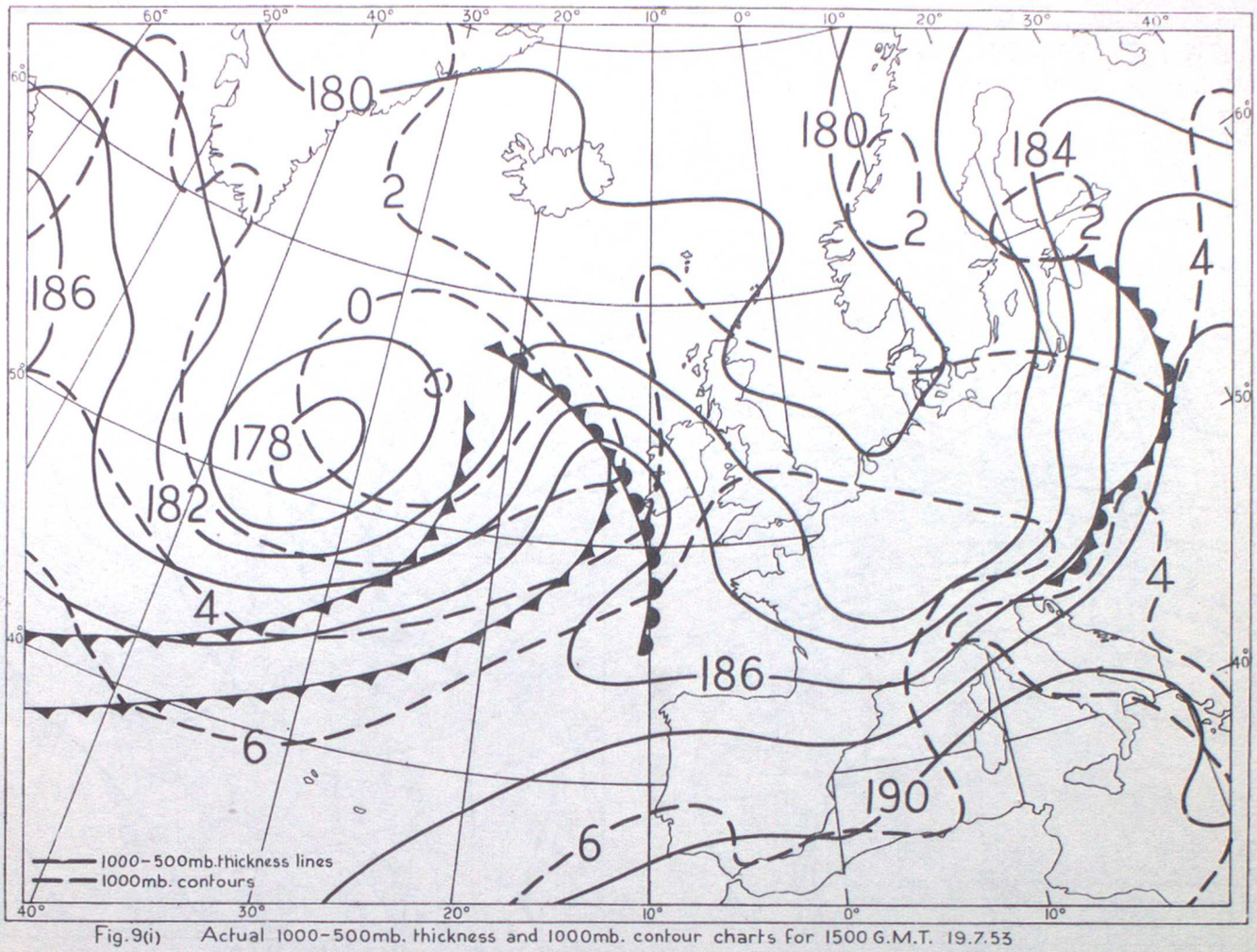

Fig. 9(i) Actual 1000–500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 19.7.53

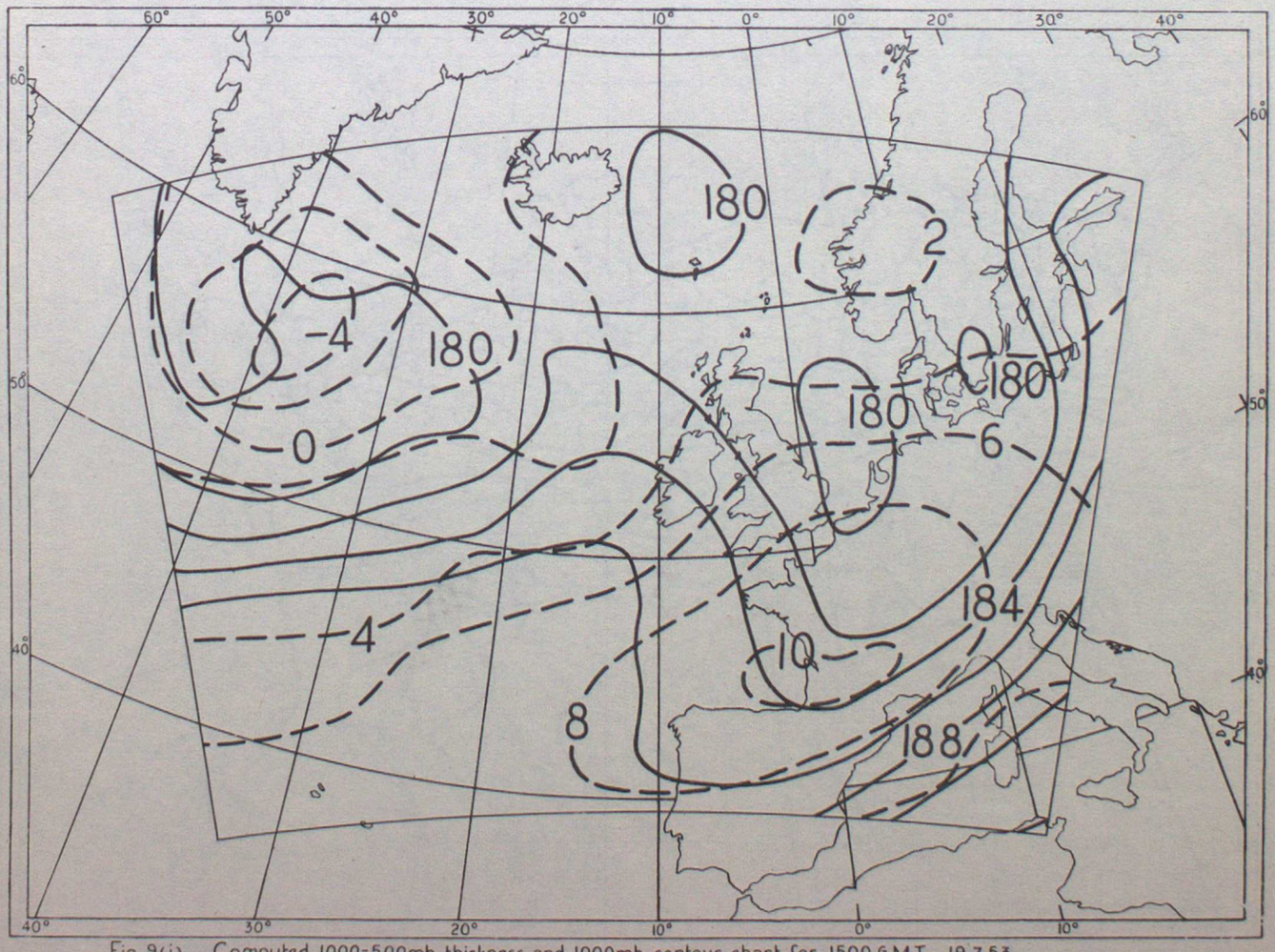

Fig. 9(j) Computed 1000–500mb. thickness and 1000mb. contour chart for 1500 G.M.T. 19.7.53

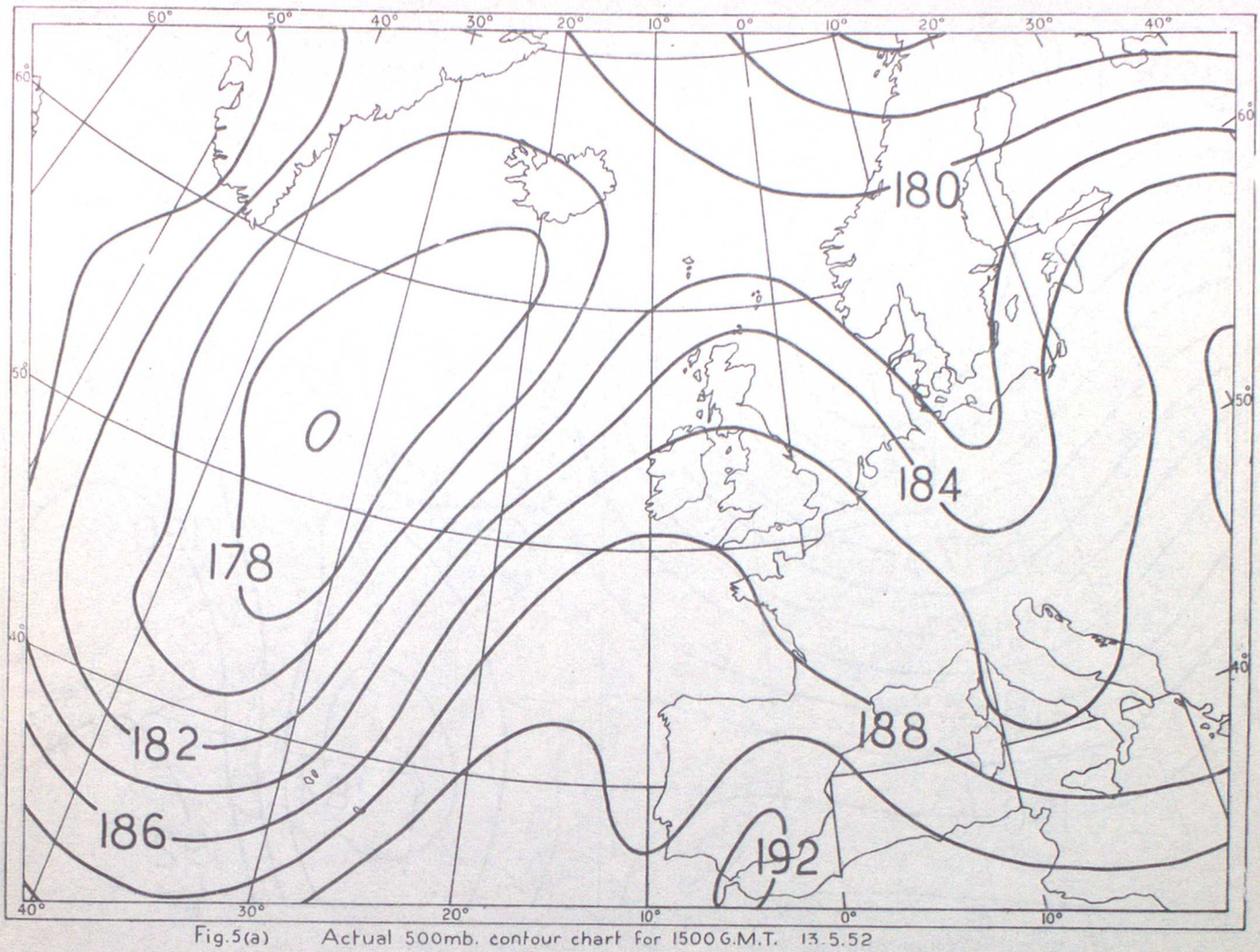

Fig.5(a) Actual 500mb. contour chart for 1500 G.M.T. 13.5.52

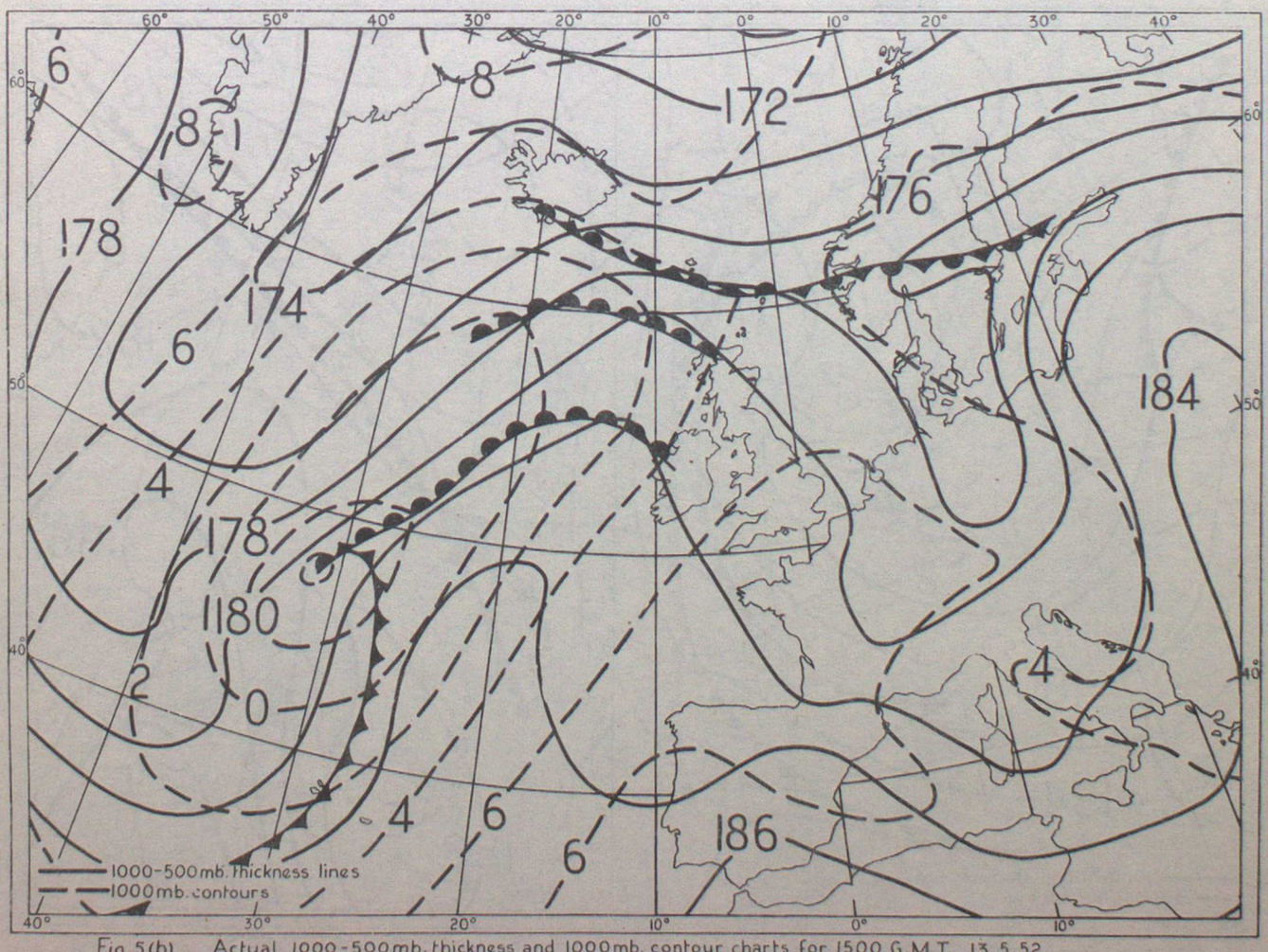

Fig.5(b) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 13.5.52

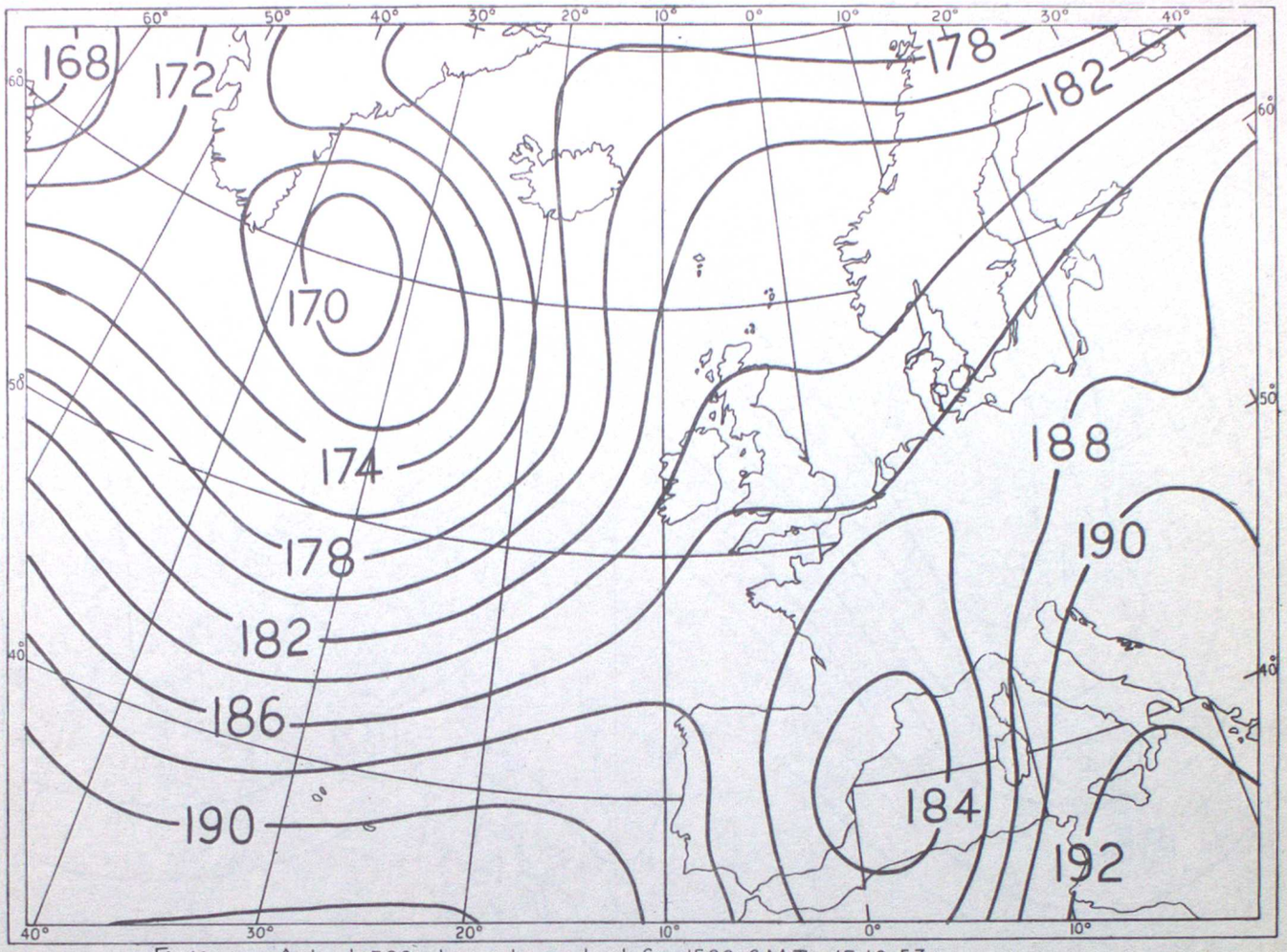

Fig.10(a) Actual 500mb. contour chart for 1500 G.M.T. 15.10.53

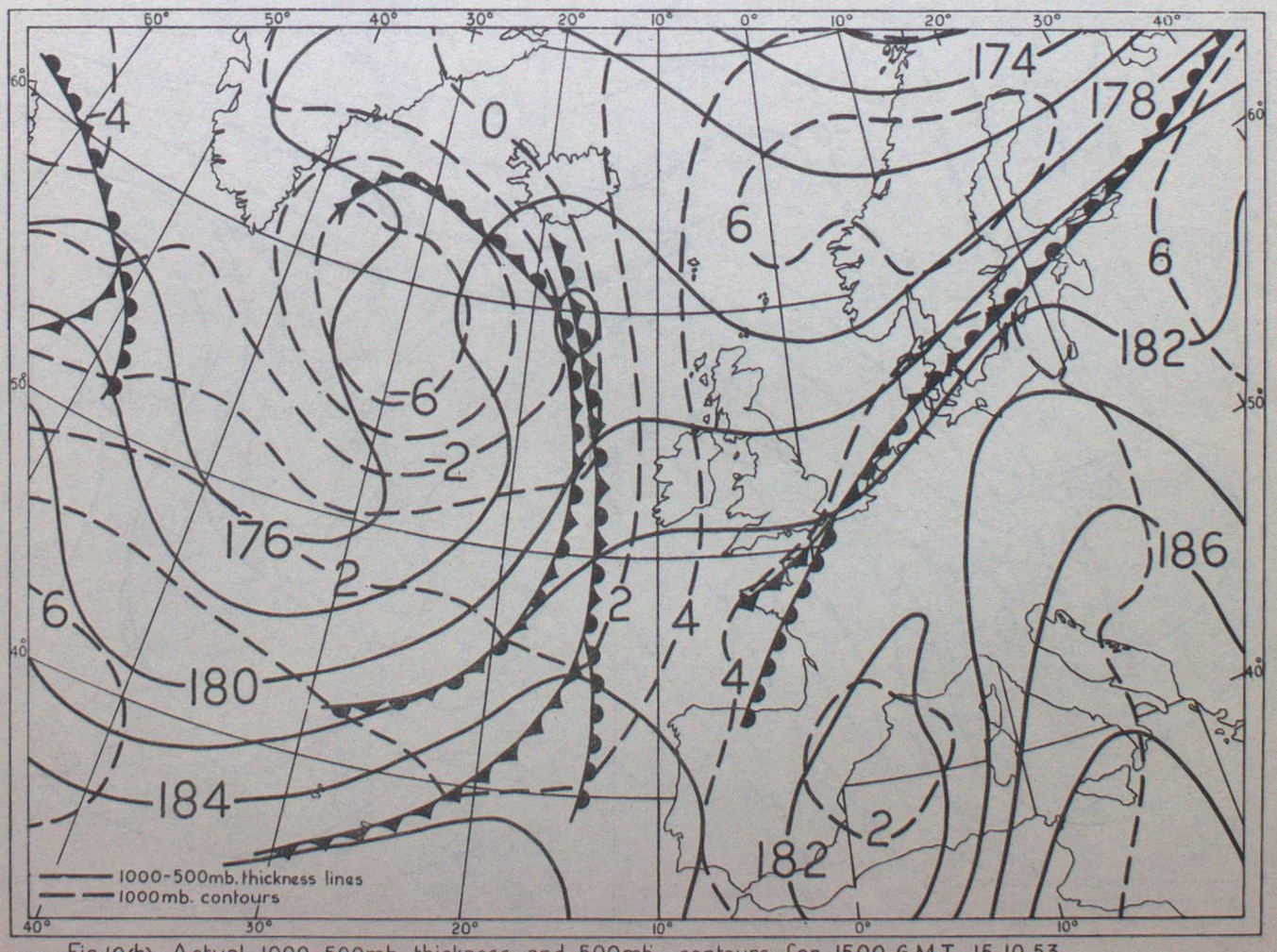

Fig.10(b) Actual 1000-500mb. thickness and 500mb. contours for 1500 G.M.T. 15.10.53

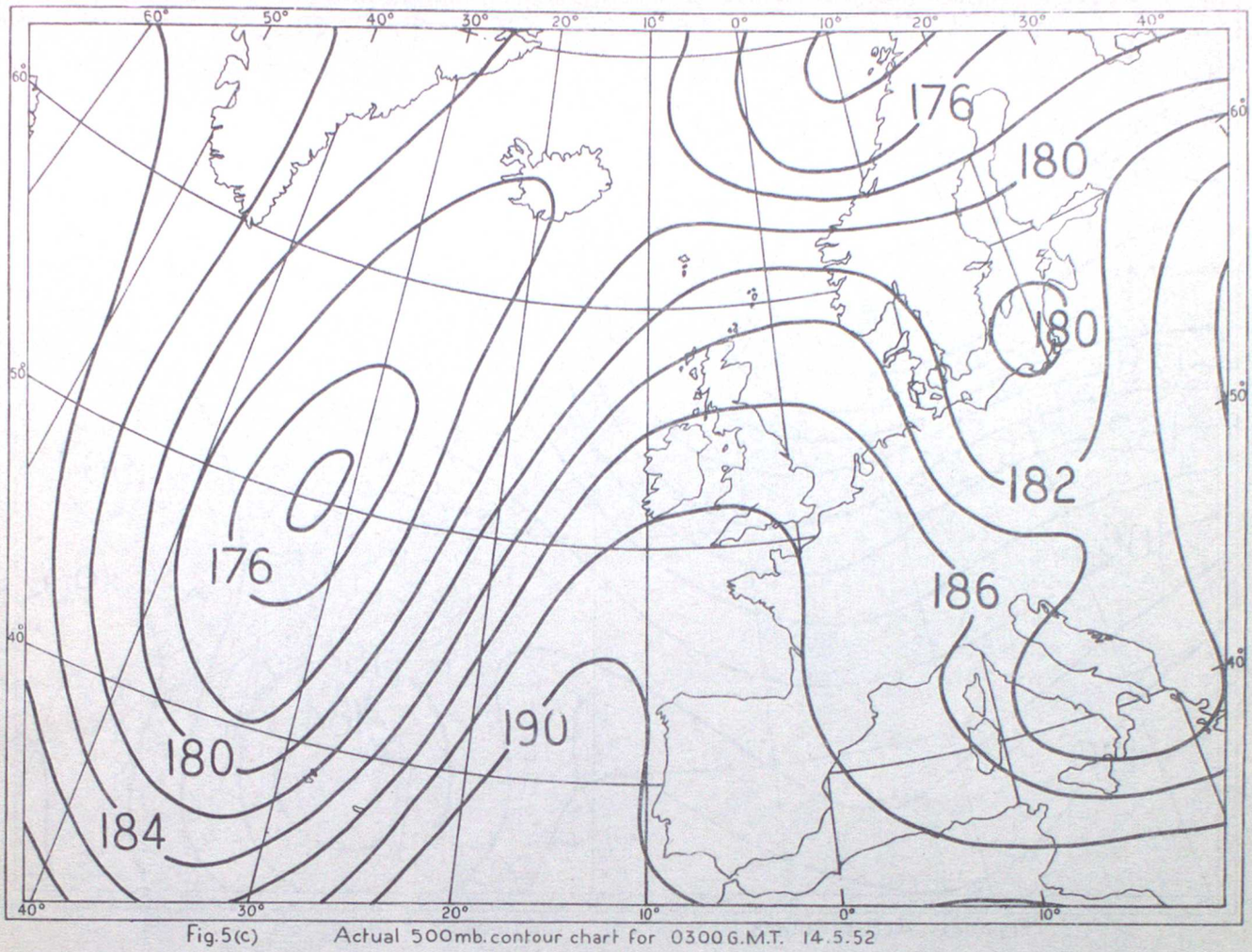

Fig.5(c) Actual 500mb. contour chart for 0300 G.M.T. 14.5.52

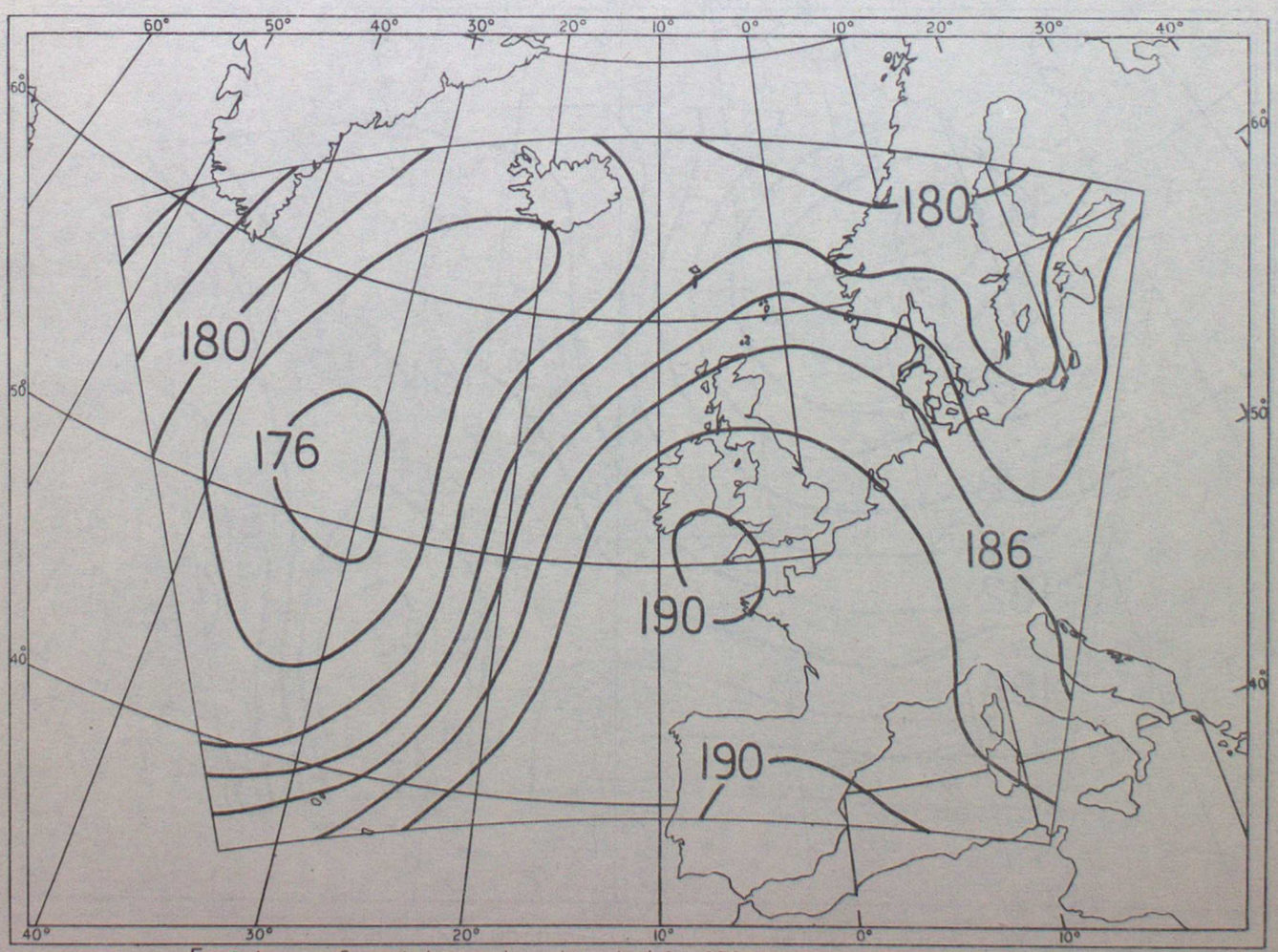

Fig.5(d) Computed 500mb. contour chart for 0300 G.M.T. 14.5.52

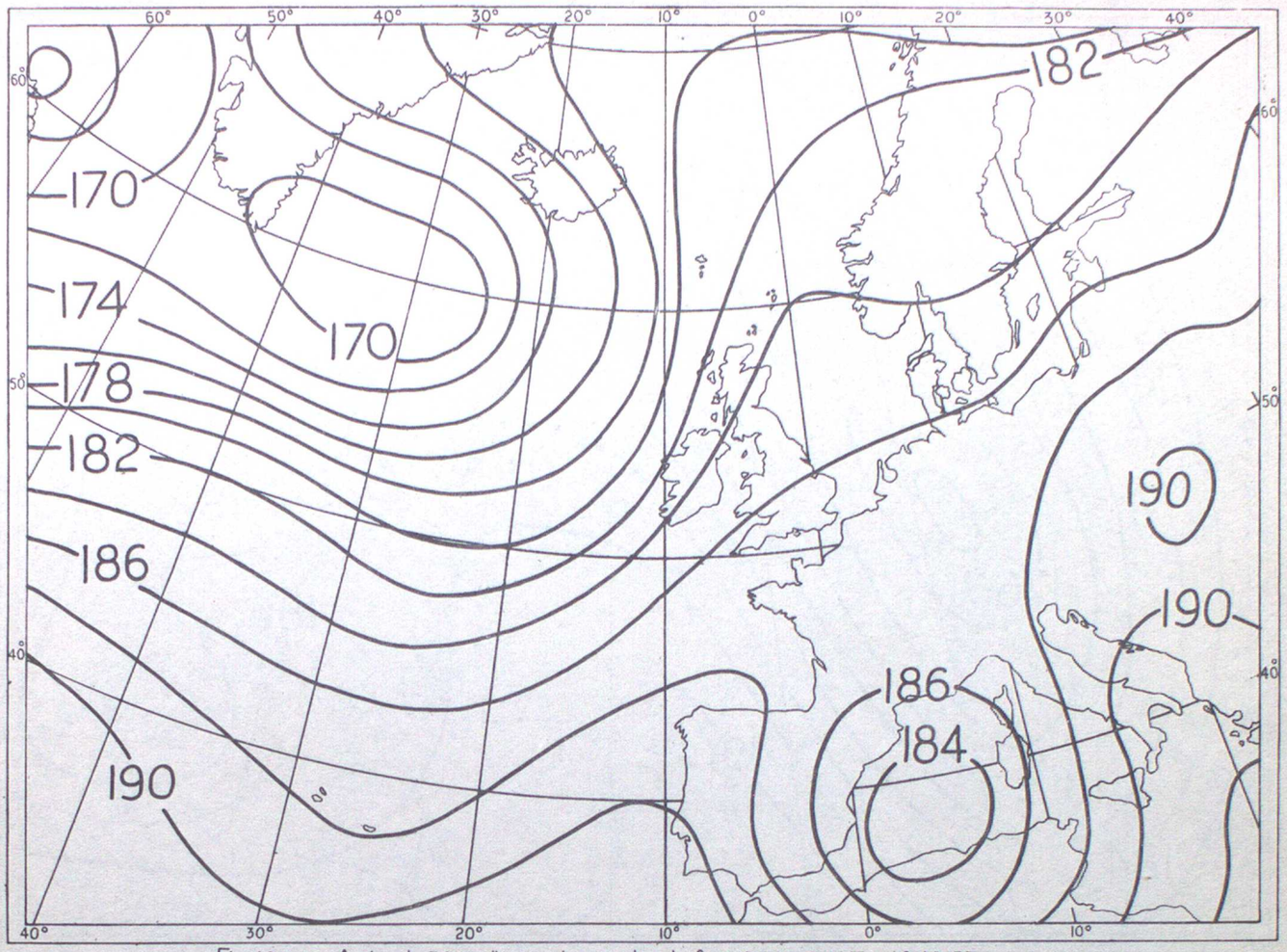

Fig.10(c) Actual 500mb. contour chart for 0300 G.M.T. 16.10.53

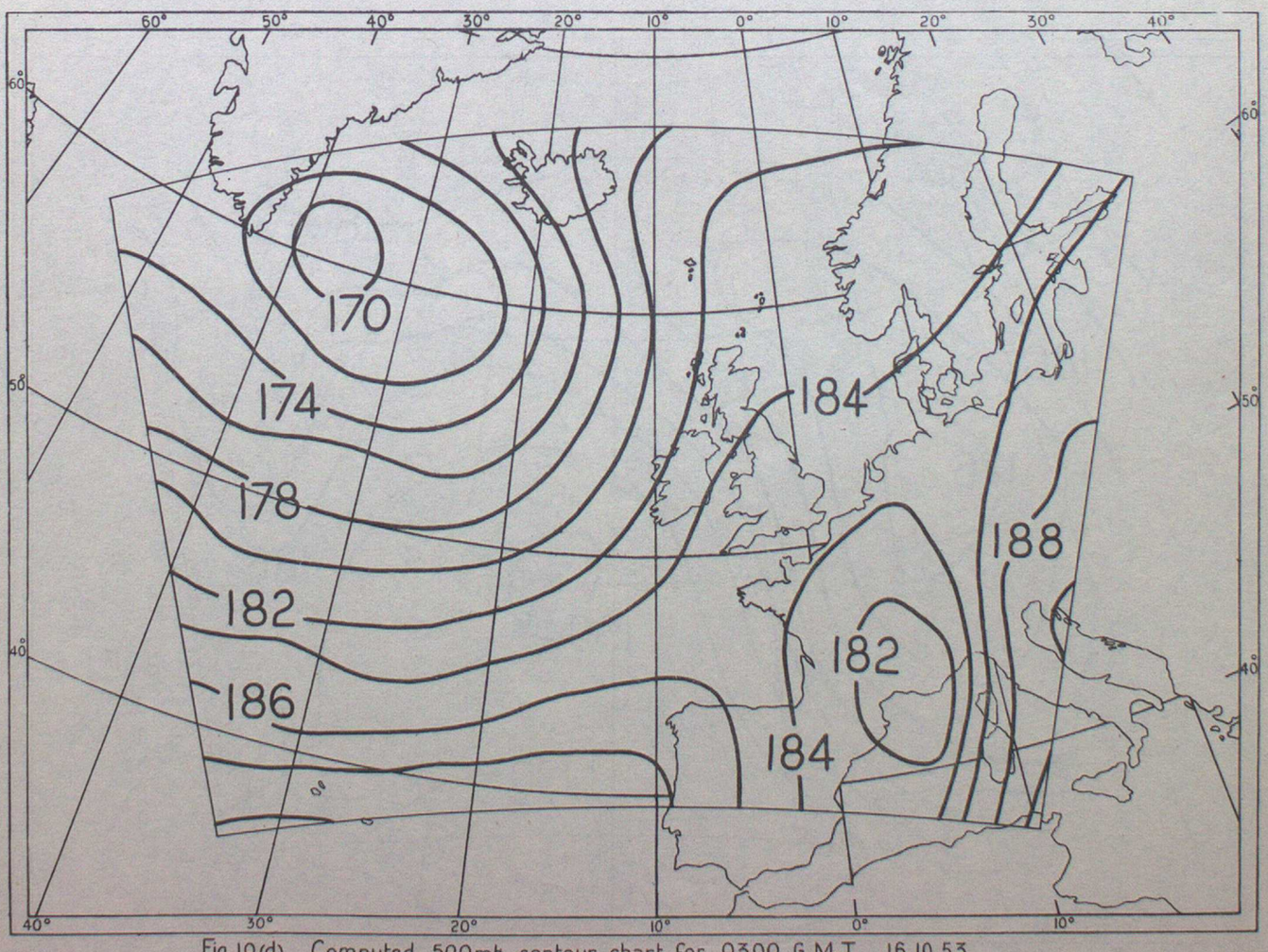

Fig.10(d) Computed 500mb. contour chart for 0300 G.M.T. 16.10.53

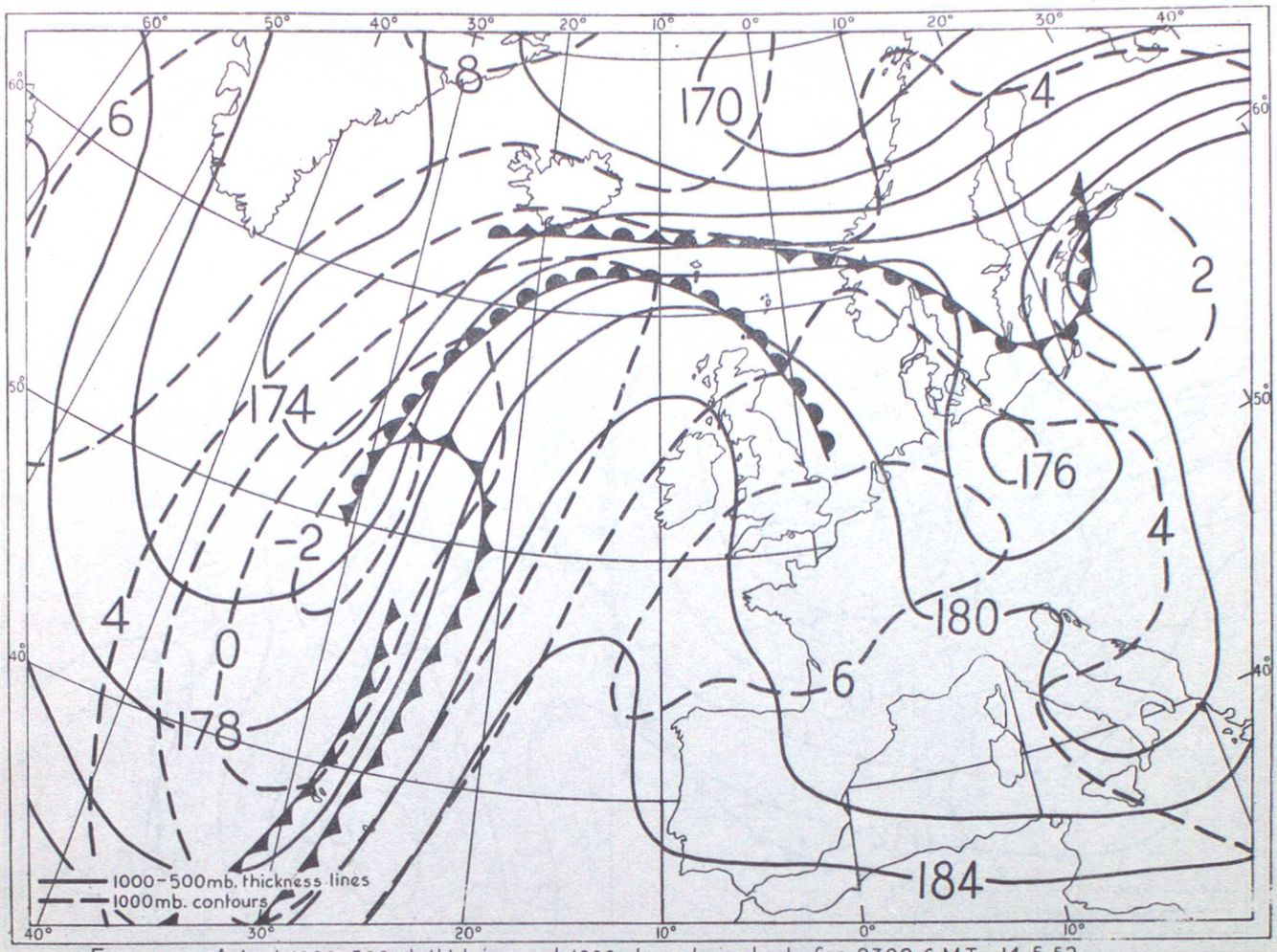

Fig.5(e) Actual 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 14.5.52

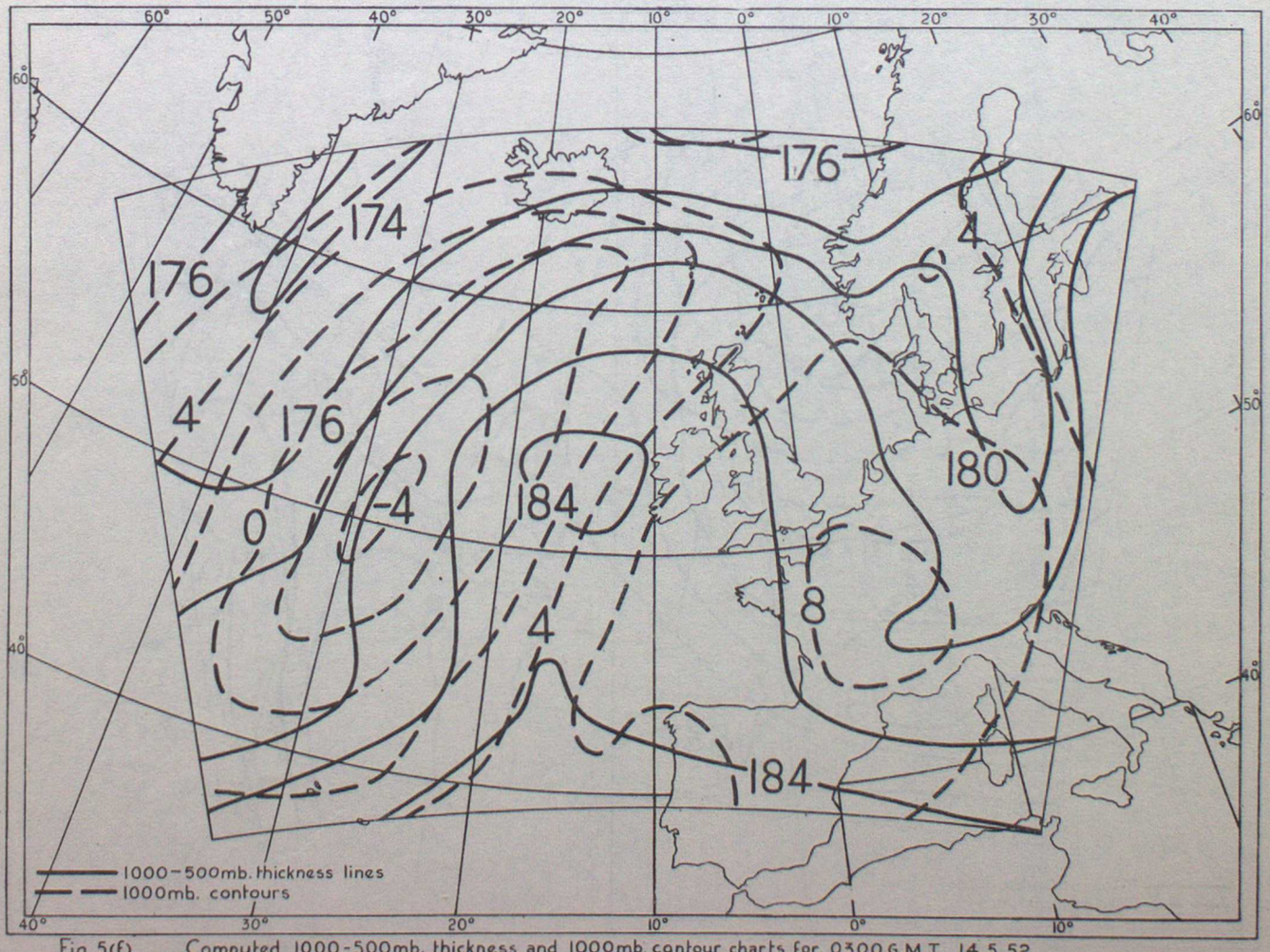

Fig.5(f) Computed 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T. 14.5.52

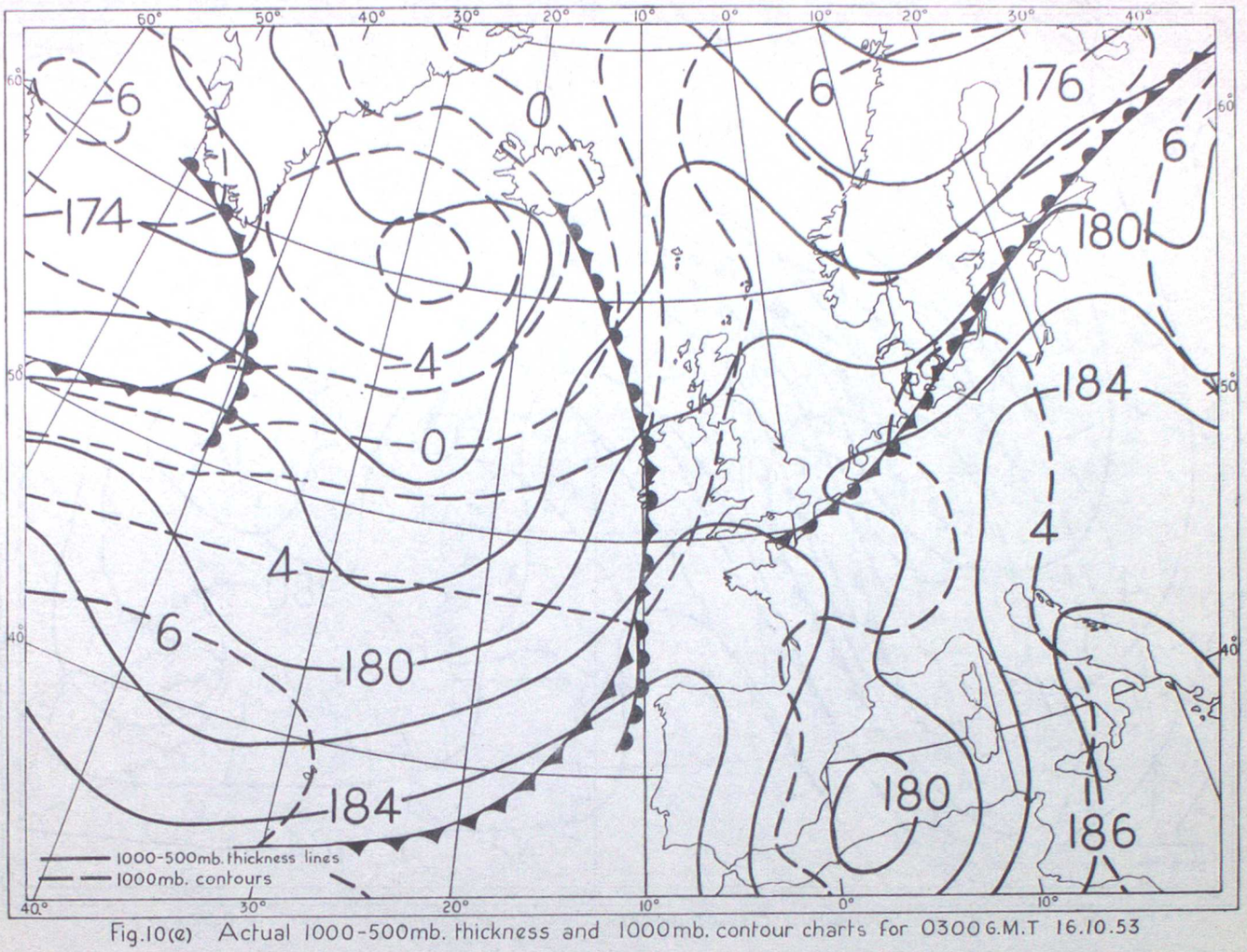

Fig.10(e) Actual 1000-500mb. thickness and 1000mb. contour charts for 0300 G.M.T 16.10.53

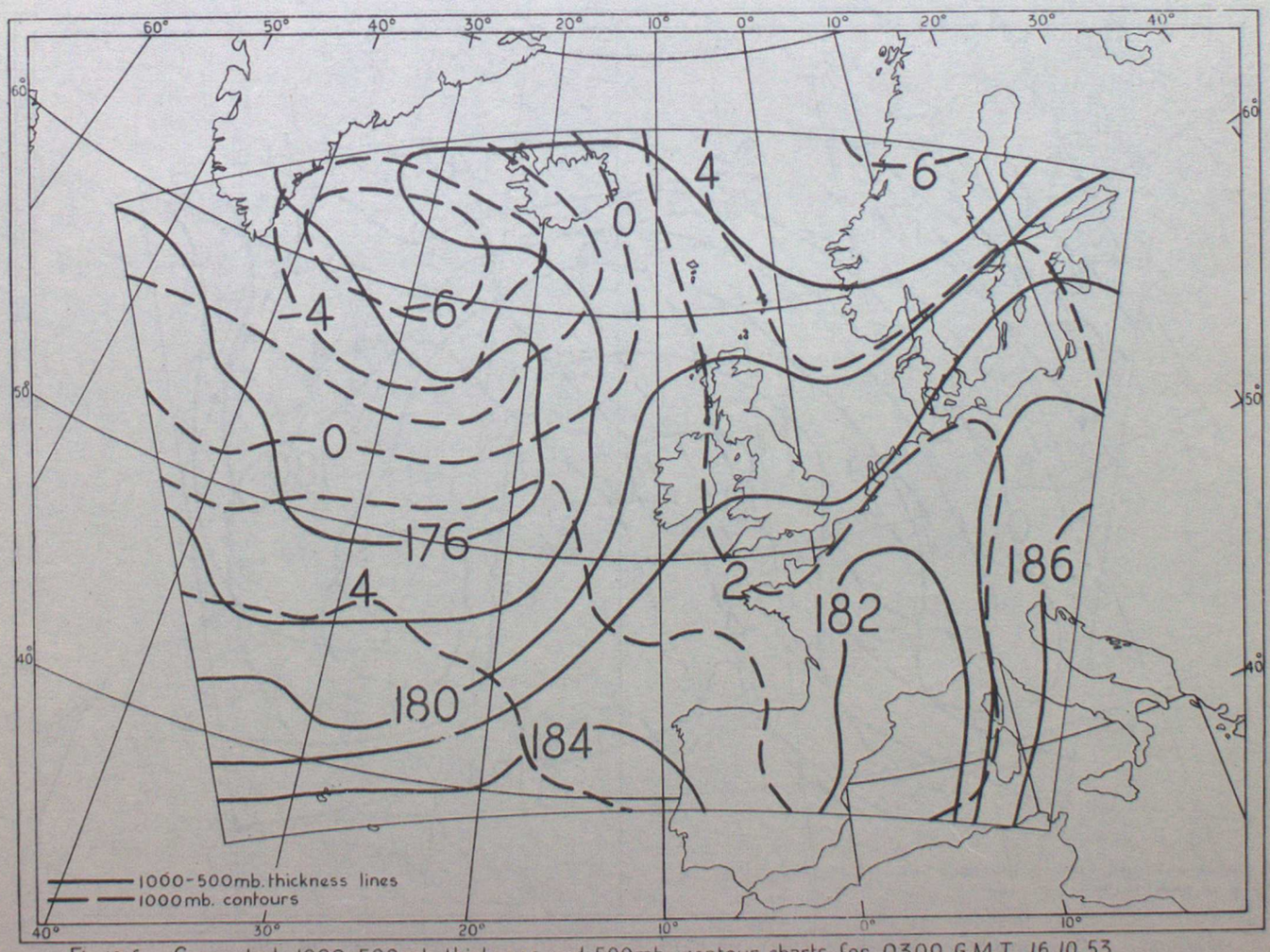

Fig.10(f) Computed 1000-500mb. thickness and 500mb. contour charts for 0300 G.M.T. 16.10.53

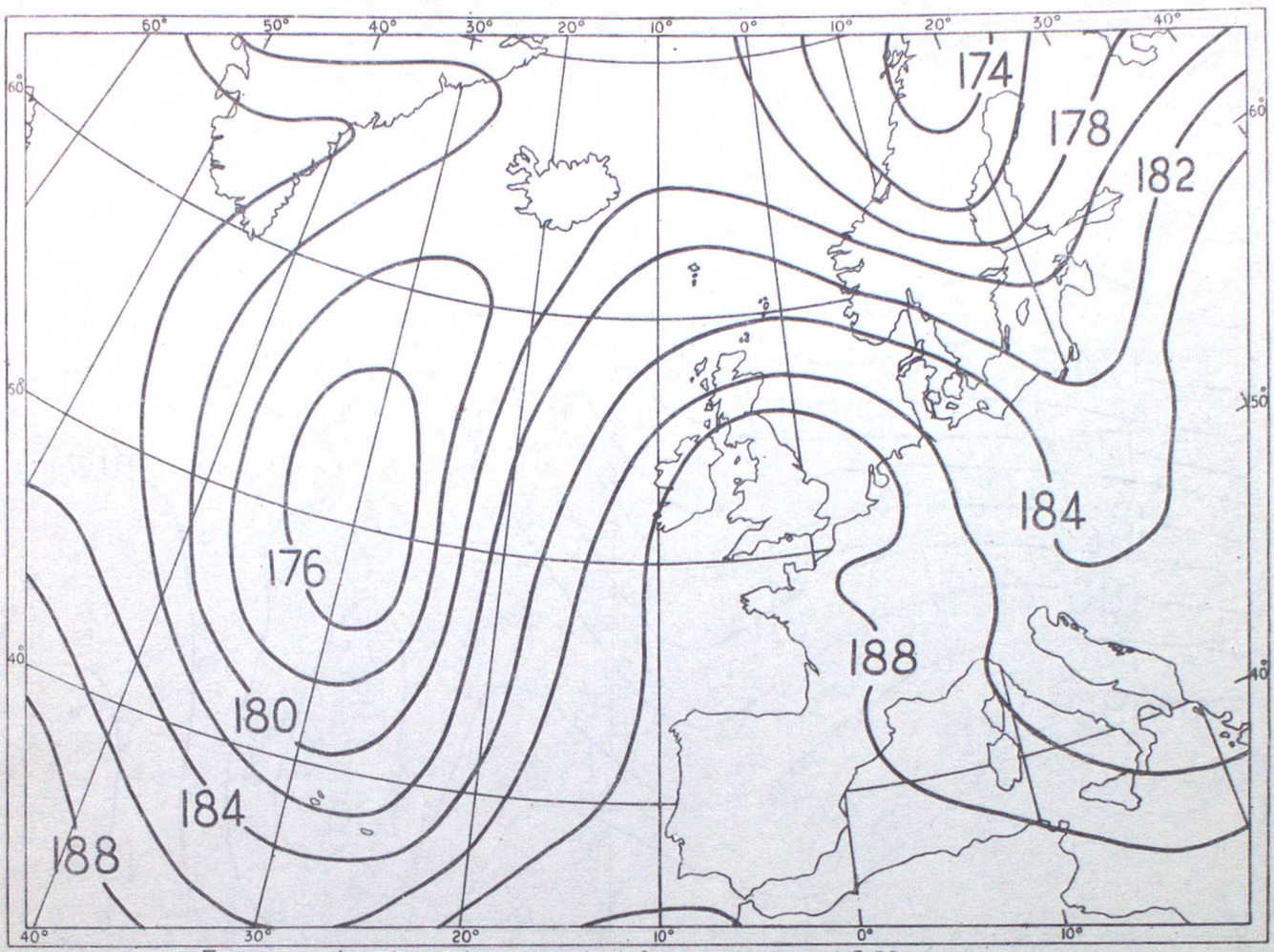

Fig.5(g) Actual 500mb. contour chart for 1500 G.M.T. 14.5.52

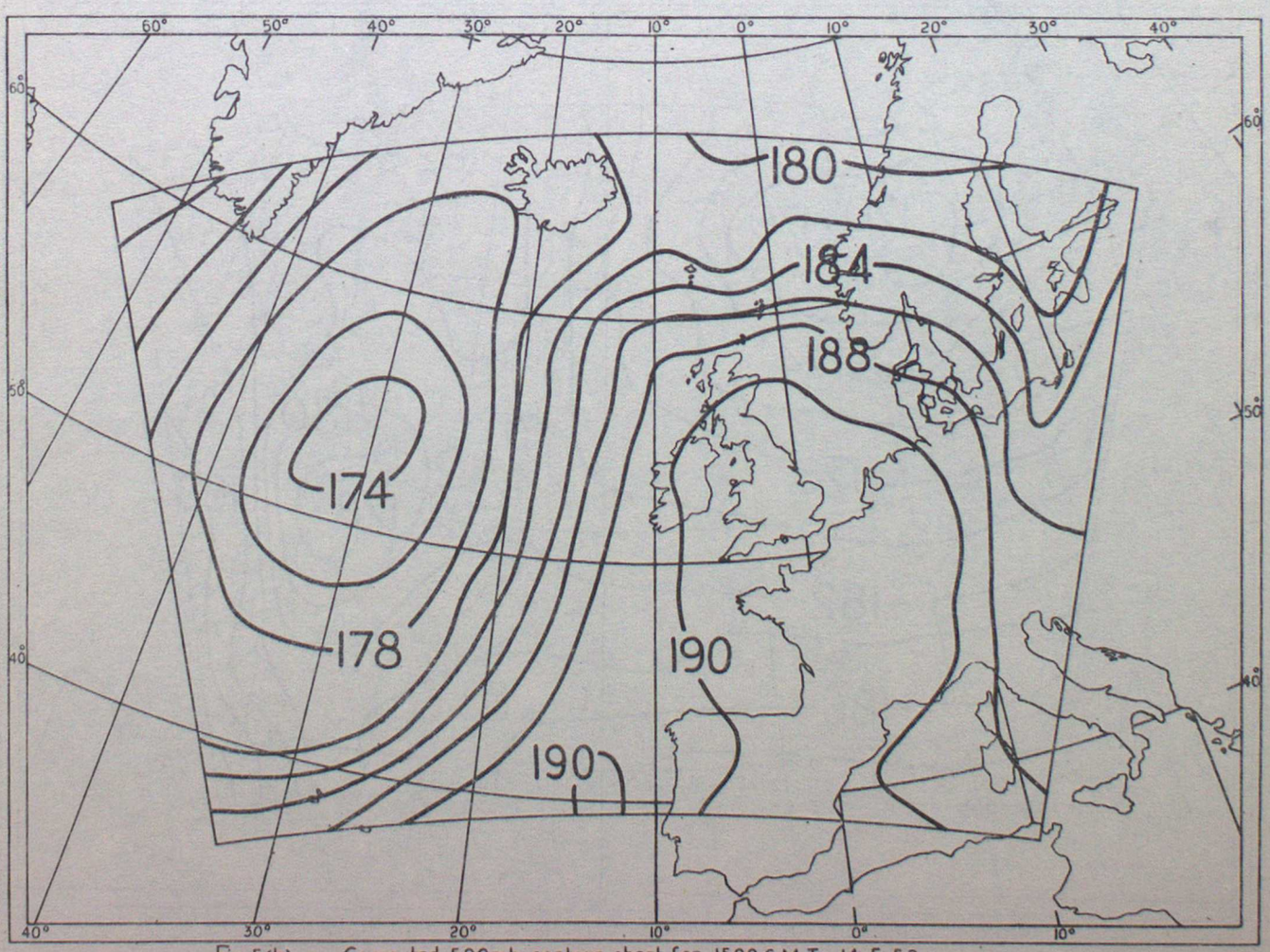

Fig.5(h) Computed 500mb. contour chart for 1500 G.M.T. 14.5.52

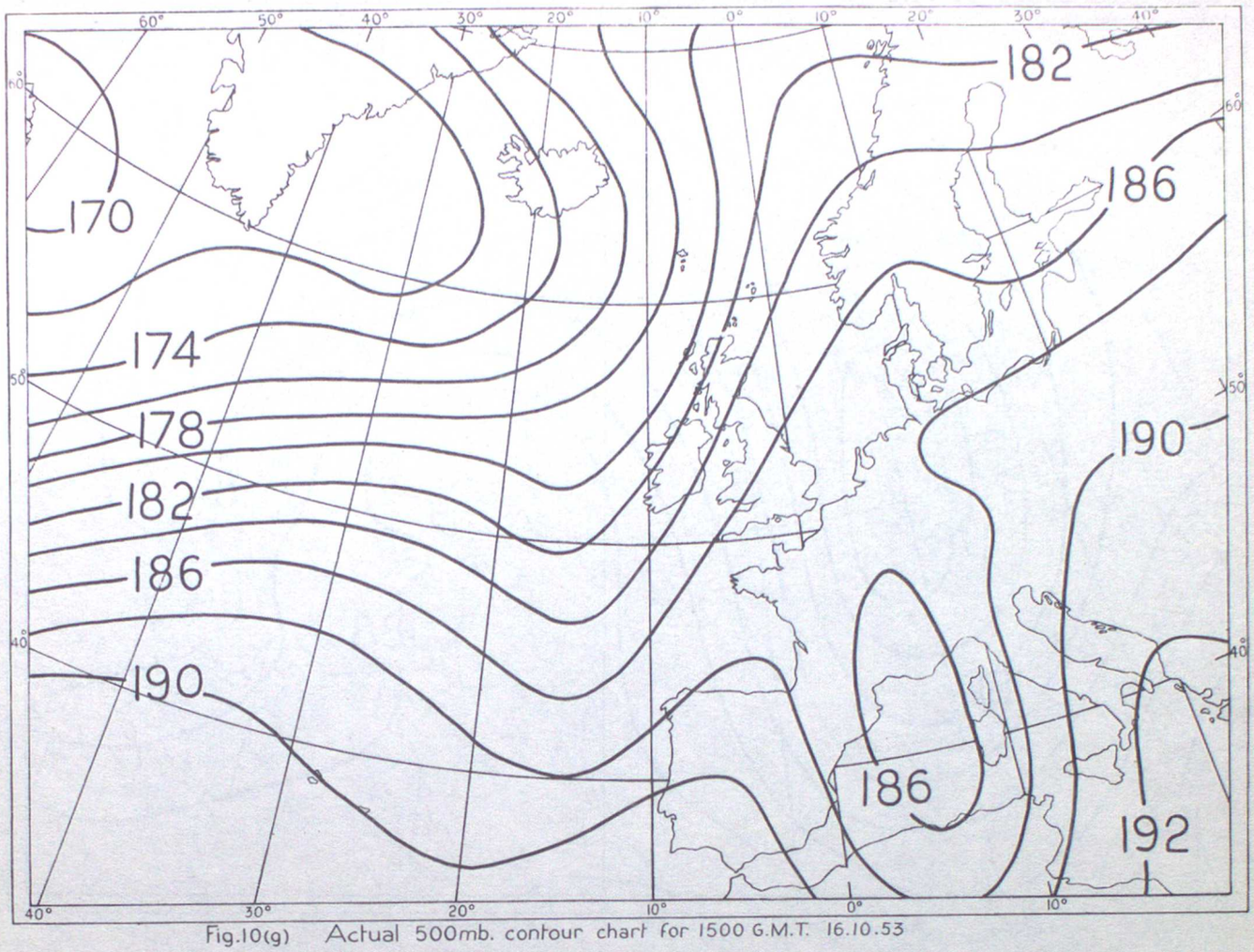

Fig.10(g) Actual 500mb. contour chart for 1500 G.M.T. 16.10.53

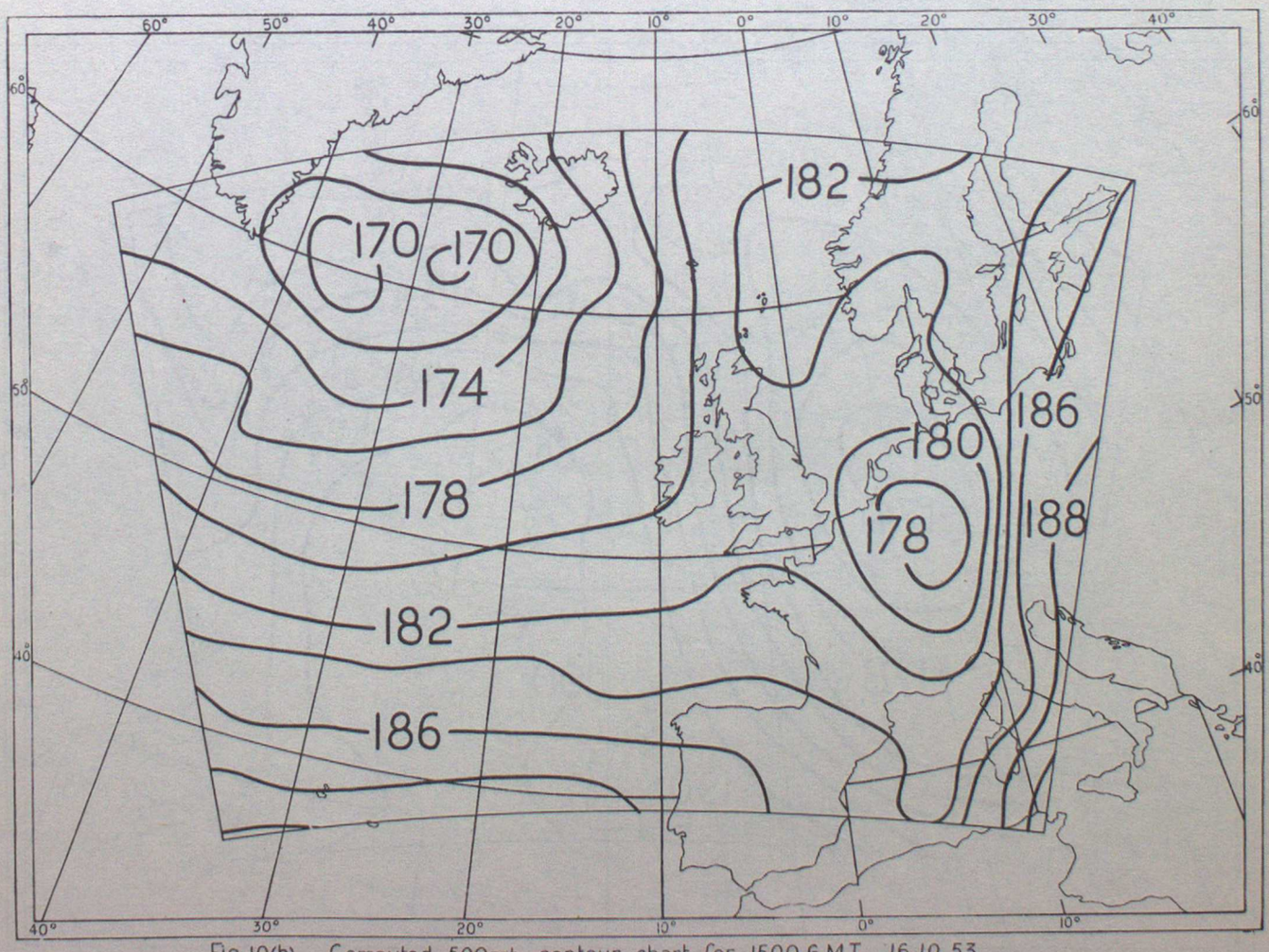

Fig.10(h) Computed 500mb. contour chart for 1500 G.M.T. 16.10.53

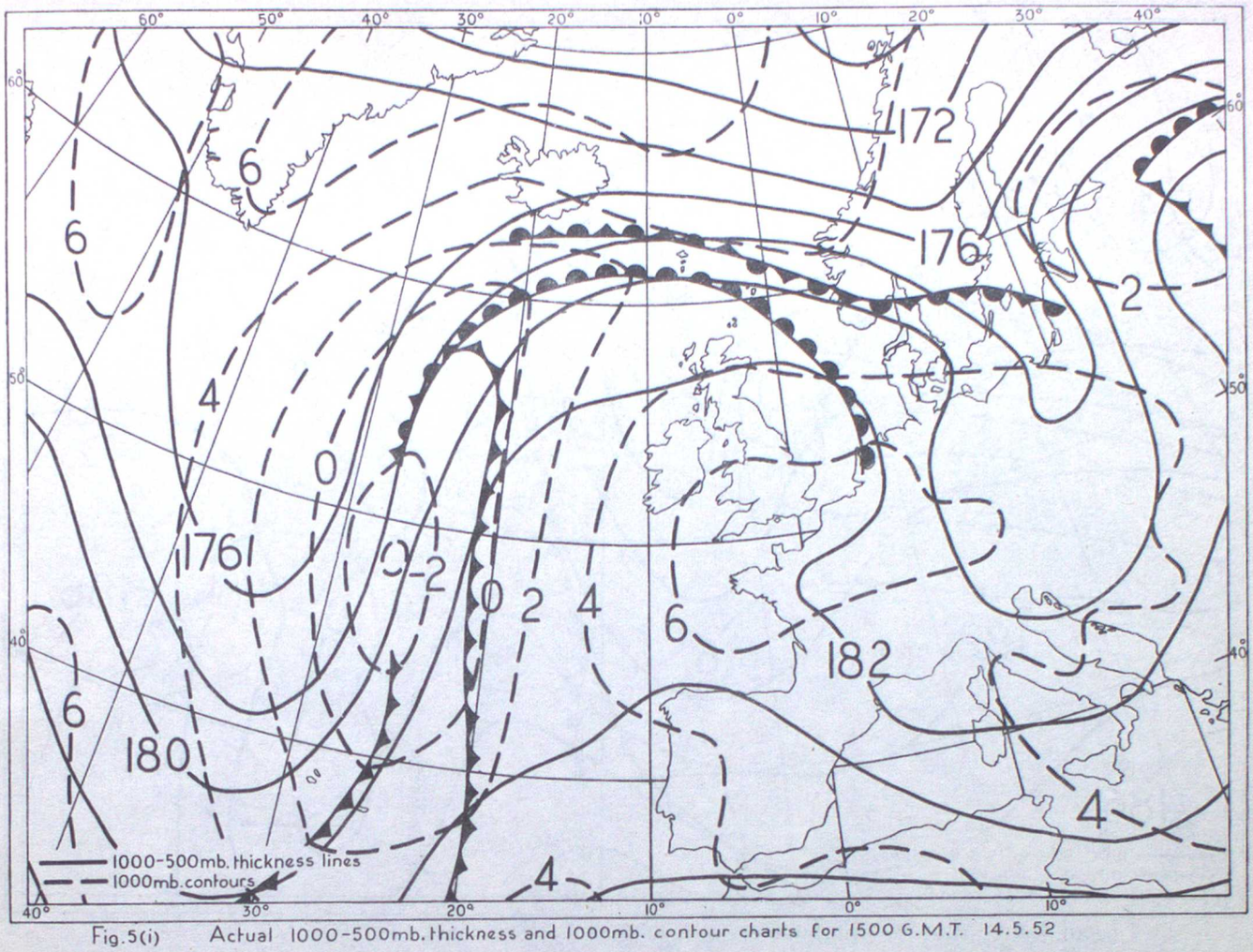

Fig.5(i) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 14.5.52

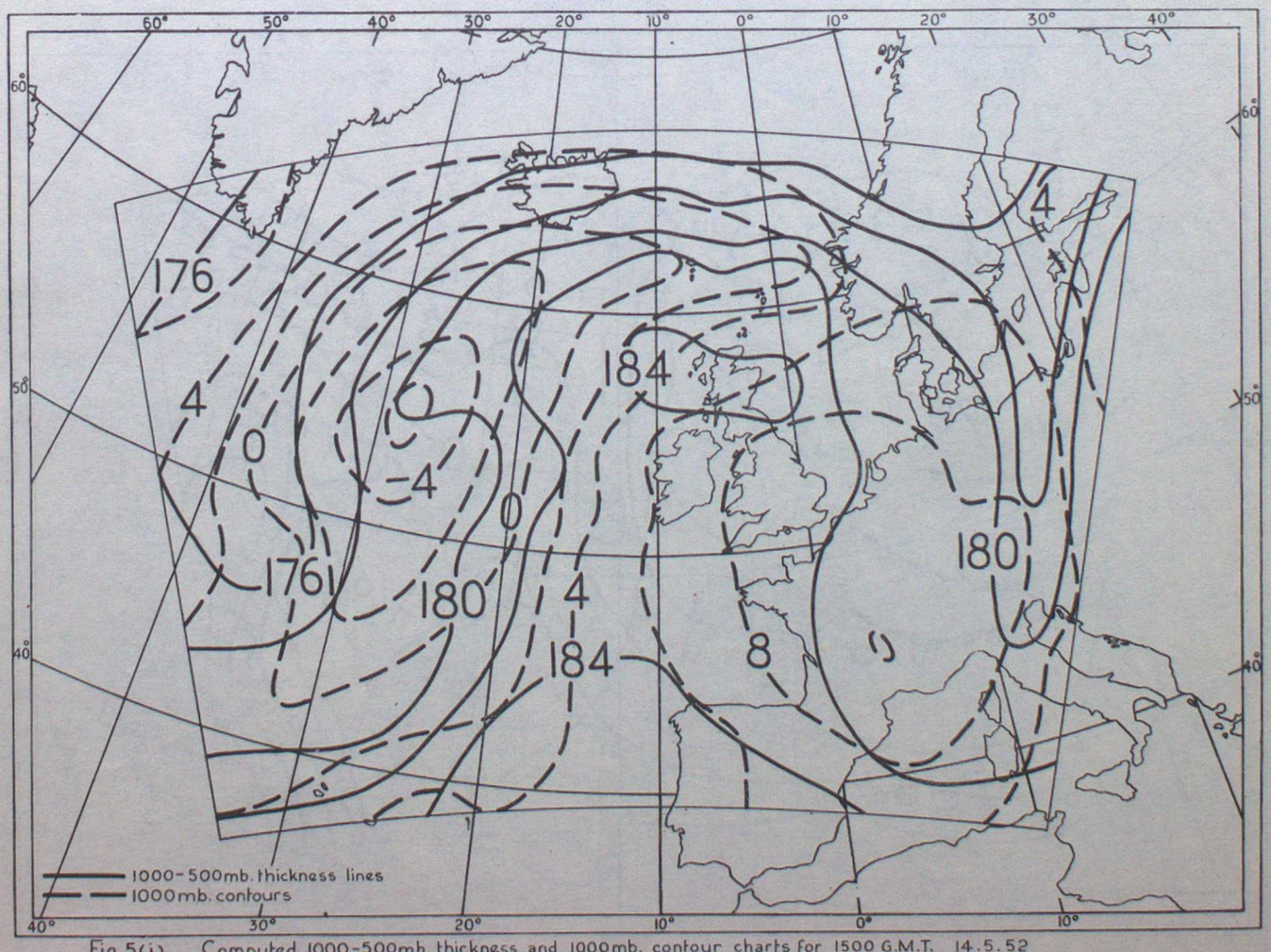

Fig.5(j) Computed 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 14.5.52

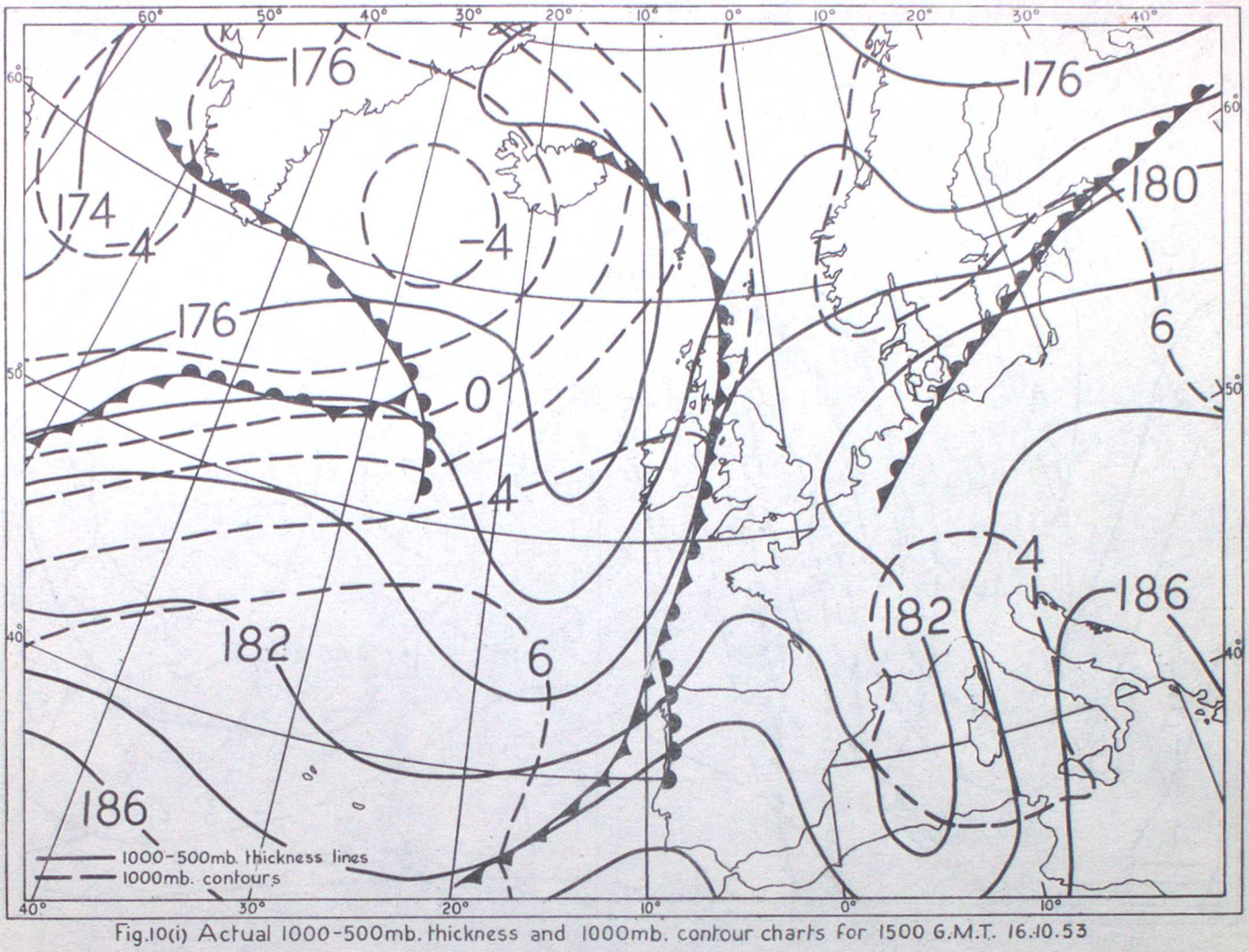

Fig.10(i) Actual 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 16.10.53

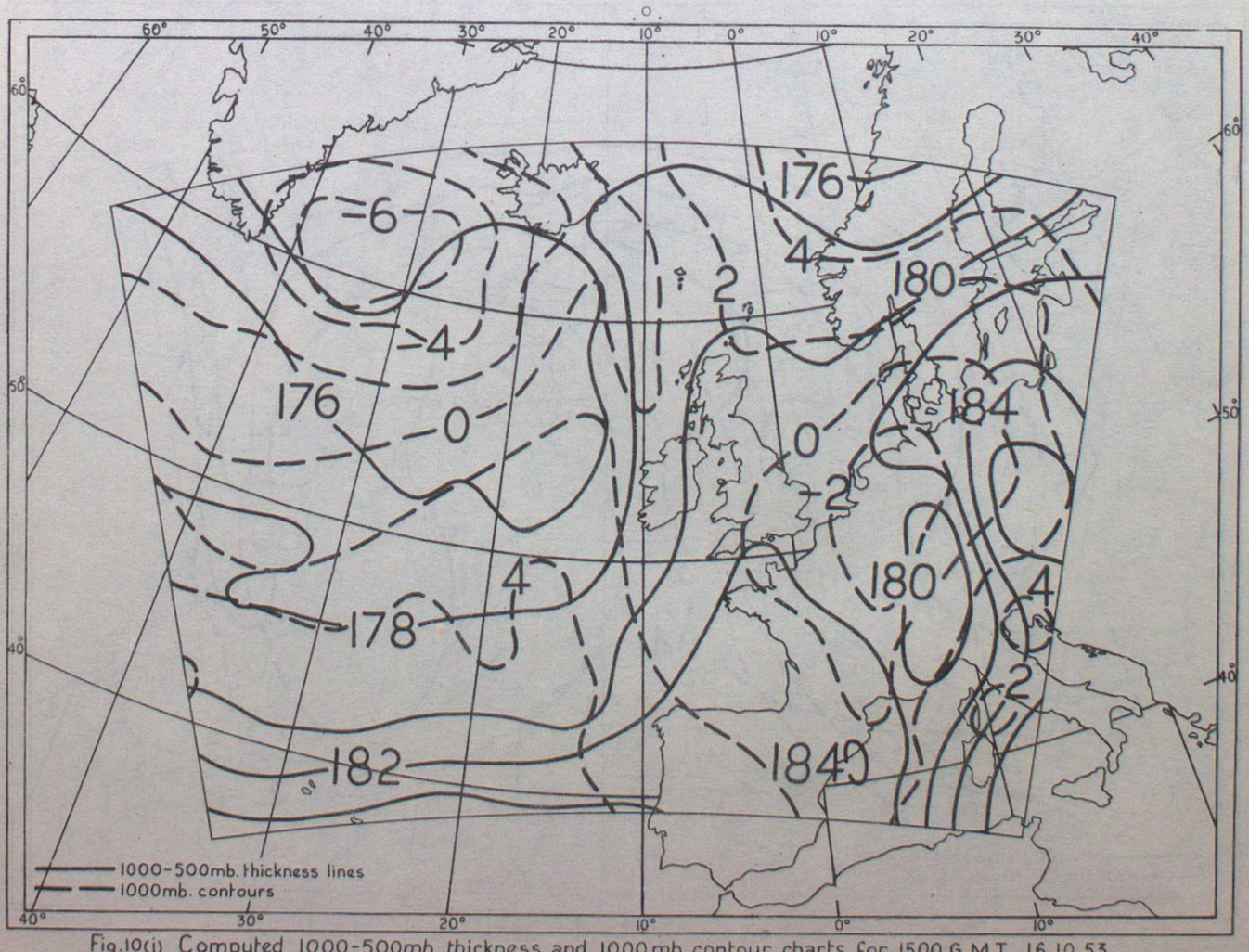

Fig.10(j) Computed 1000-500mb. thickness and 1000mb. contour charts for 1500 G.M.T. 16.10.53